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Final Report to the President

Advisory Committee on the Redesign of the Space Station

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June 10, 1993

The President's Advisory Committee on the Redesign of the Space Station

June 10, 1993

The Honorable Al Gore
Office of the Vice President
Old Executive Office Building
Washington, D.C. 20501

Dear Mr. Vice President:

I am pleased to forward this Report of the Advisory Committee on the Redesign of the Space Station. This committee has worked on its assessment of the redesign since April 22, 1993. It has assessed the various redesign options developed by NASA's Station Redesign Team on the basis of technical and scientific capability, accuracy of projected costs, and structure of management and operations, The first-level goals for the space station, as stated in Dr. John Gibbon's letter of April 30, 1993, served as a guide during this assessment.

Throughout this assignment we have been extremely pleased with the effectiveness and responsiveness of the Redesign Team. This diverse and committed group of men and women has performed in an exemplary manner while executing a complex and difficult task under severe time constraints. We also wish to note the cooperative and collegial manner in which our international partners, representing the Canadian Space Agency, the European Space Agency, the Science and Technology Agency of Japan, and the Italian Space Agency, worked with us throughout this process.

The civil space program and the scientific and technological advances it makes possible are of urgent importance to a forward-looking nation. The members of our committee further believe that there is great intrinsic value in human presence in space. Yet our civil space program is in need of clear goals and missions, and we recognize that the pace and intensity of development, research, and exploration in space must be carefully scrutinized in light of national budgets and priorities. It is our firm belief that the Administration and the Congress must make a clear and long-lived decision regarding the space station. We hope that this report will be of assistance in reaching that decision.

Respectfully,

Charles M. Vest

Charles M. Vest

PREFACE

The members of this committee came to this task from varied backgrounds and experiences in the space program, industry, academia, and the military. We accepted this assignment in the spirit of national service to assist the Federal government in making basic decisions regarding the space station and the civil space program.

We believe in the importance of the exploration of space by both robotic and human means. We believe that international cooperation and partnership are important attributes in such undertakings. We believe that human presence in space has intrinsic value. We believe that it is possible to predict only partially the scientific, technological, and human benefits of long-duration residence, experimentation, and exploration in space.

Yet we also recognize that the pace and intensity of development, research, and exploration in space must be carefully scrutinized in light of national and international budgets and priorities. In our view, the civil space program is a very important national undertaking, but its priorities must be subjected to careful analysis of costs and benefits. It is in great need of stability of goals and budgets. The scope and costs of the space station require careful and accurate analysis and prioritization.

We hope that this report, which assesses the work of the Station Redesign Team, will contribute to credible, timely, clear, and long-lived decision-making about the future of the space station program.

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EXECUTIVE SUMMARY AND FINDINGS

Background

On March 9, 1993, the President of the United States asked NASA to undertake an effort, of 90 days duration, to redesign the Space Station Program in such a manner that major reductions in the projected costs of Space Station Freedom would be realized. The President requested that he be provided with several design options of varying cost and capability. The Administration explicitly selected this course of action in preference to continuing to develop Space Station Freedom or to canceling plans to establish a space station altogether.

On March 10, 1993, under the direction of NASA Administrator Daniel Goldin, the Station Redesign Team, a hand-picked group of 45 NASA employees and 10 representatives from the international partners for Space Station Freedom, undertook this demanding task. The team was assembled, and was led initially by Dr. Joseph Shea, and subsequently by Col. Bryan O'Connor.

On March 25, 1993, Vice President Albert Gore appointed Dr. Charles Vest to chair an Advisory Committee on the Redesign of the Space Station. Sixteen experts with varied backgrounds and experiences in the space program, industry, academia, and the military were appointed to this Advisory Committee (Appendix A). They were supplemented by a small number of additional experts to assist in analyzing specific aspects of the redesign. The Advisory Committee also worked in close collaboration with representatives of NASA's international partners, the Canadian Space Agency, the European Space Agency, the Science and Technology Agency of Japan, and the Italian Space Agency, as ex officio members of the Advisory Committee.

During the work of both the Station Redesign Team and the Advisory Committee, the U.S. Office of Science and Technology Policy issued two important statements. The first requested that the Redesign Team consider what viable space station options that continue to accommodate the international partners could be delivered at three cumulative-cost levels for the period Fiscal Year 1994 to Fiscal Year 1998: $5 billion (with a peak annual funding of $1 billion), $7 billion (with a peak annual funding of $1.5 billion), and $9 billion (with a peak annual funding of $1.8 billion). The second was a statement, developed at the request of the Advisory Committee, of the Administration's first-level goals for the space station, and their articulation of preliminary goals for the overall civil space program. These statements are included in this report as Appendices B and C. The Advisory Committee's assessments of the redesign options included consideration of these goals.

The task of the Advisory Committee was to assess the Station Redesign Team's recommended designs on three fundamental grounds: technical and scientific capability, accuracy of projected costs, and structure of management and operations. In other words, will each redesign option accomplish its stated objectives; will the actual costs during the coming years likely be those projected by the team; and will the recommended management structure be appropriate to accomplish the task? The report includes an independent assessment by the international partners.

The Station Redesign Team developed three basic options, which are described in detail in their *Space Station Redesign*

Team Final Report to the Advisory Committee on the Redesign of the Space Station and in a summary fashion in this report in the section titled "Description of the Options." Two of these designs, Options A and B, are largely derivative of Space Station Freedom. Both grow over time in a modular fashion by attaching elements (solar power panels, heat-rejection surfaces, habitation and laboratory modules, experimental packages, and a robotic servicing system) to a large truss structure, and also make various uses of docked space shuttle orbiters. Option C does not use a truss structure, but instead has as its core element a large pressurized cylindrical habitation and experimentation module that is lofted into orbit in a single launch. Solar arrays and heat-rejection surfaces are attached to this basic element, and various other modules can be attached to the core as it evolves. This option draws substantially on knowledge and technology developed for the Space Shuttle Program.

Each of the options requires a large number of space shuttle flights for assembly and tending, and each evolves to different stages of development and capability. Milestones include attainment of human-tended capability, international presence, and permanent human capability. A minimal configuration, a power station, consisting only of a structure with solar panels to generate electrical power to which a space shuttle can be attached, is possible in Options A and B. This variety of developmental stages makes a simple comparison difficult.

Advisory Committee Organization and Operation

The Advisory Committee was divided into four subcommittees: Technical and Mission Assessment (Dr. Albert Wheelon, Chair), Science, Applications, and Technology Research Assessment (Dr. Louis Lanzerotti, Chair), Cost Assessment (Mr. Jay Chabrow, Chair), and Management and Operations Assessment (Dr. Mary Good, Chair).

The Advisory Committee interacted substantially with the NASA Administrator and the Redesign Team in an open, candid, and collegial manner, while being careful to maintain its independence and objectivity.

The entire Advisory Committee held three two-day meetings, on April 22–23, May 3–4, and June 7–8, 1993. Typically, the first day was devoted to public meetings of the full committee reviewing the status and development of the redesign options. The second day was spent primarily in subcommittee working sessions. The subcommittees, and, as appropriate, individual members, interacted with the Redesign Team, visited NASA facilities for in-depth briefing and fact-finding, and contacted various members of the industrial and academic research communities.

During the course of the assessment effort, it became important to understand the baseline design parameters and costs of Space Station Freedom. To attain this understanding, the Cost Assessment subcommittee worked closely with the Redesign Team and with NASA's Independent Cost Assessment Team. The Committee also reviewed and utilized the results of NASA's Requirements Assessment Group Report, which evaluated the research community's specifications and needs for a space station.

Basic Findings

The Committee's key findings in seven areas of assessment are summarized below. Additional findings and more detailed substantive information are included in the balance of this document.

General. Several of the findings are applicable to the assessment of the redesign activity or the more general question of an orbiting space station. They are:

- The Station Redesign Team was highly competent, and its work has been effective in providing the Advisory Committee and the President with several design options covering a range of cost and capability.
- The space station should be considered as an ongoing, evolving program of scientific and technological research conducted in an orbiting national and international research laboratory that is part of the Nation's high-technology infrastructure.
- The space station is an international cooperative venture requiring long-term multilateral commitment.
- Scientific and technological research and development projects should be selected for implementation on the station on the basis of unique requirements for long-duration residence in an orbital environment and the degree to which human interaction is required. Scientific knowledge of the effects of long-duration spaceflight on humans should be gained as background for future space exploration.
- The Advisory Committee believes that several considerations of safety, flexibility, and redundancy of launch and assured crew return vehicles argue strongly for launching the station at an orbital inclination that allows access by as many spacefaring nations as possible. An inclination of 51.6° would achieve this, and would enable Russian participation, thereby potentially reducing costs and enhancing international cooperation. Alternative orbits could also be considered. An expeditious decision about orbital inclination is required.

Options. This report discusses the design options themselves and the criteria by which they were evaluated. The Committee's general findings regarding the options are:

- Options A and C are the designs most deserving of further consideration. Although the general parameters and assessment of all options developed by the Redesign Team are presented, most of the Committee's work focused on these two options.
- Development limited to the power station capability is not a worthwhile option for the nation to pursue. Human-tended capability is a marginal level of development because experiments requiring the presence of crew members would be limited to a 30-day duration, greatly reducing the justification of a space station.
- The options differ in the pace at which they reach various stages of development, such as when the various international modules become integrated.

Cost. The costs of the redesign options, and of Space Station Freedom, were the focus of much of the Committee's effort. Our review of the input, methodology, and conclusions drawn by the Redesign Team provides confidence in the realism of their cost estimates. Our cost analysis subcommittee received voluminous data displaying estimating techniques, includ-

Orbital Inclination 28.8°	Space Station Freedom Baseline		SSF NASA Cost Assessment		Option A		Option B		Option C	
Phases	$	Date	$	Date	$	Date	$	Date	$	Date
Power Station					5.7	Dec 1997	6.3	Nov 1997		
Human-Tended Capability					10.5	Jul 1998	11.8	Dec 1998		
International Human-Tended Capability					13.4	Jan 2000	16.4	Mar 2001		
U.S. Permanent Human Capability									13.7	Nov 1999
Permanent Human Capability	20.0*	Sep 2000	25.1	Mar 2001	16.5	Oct 2000	19.3	Dec 2001	15.1	Jan 2001

* Does not include assured crew return vehicle

(shaded) = not applicable

Figure 1. Space Station Cumulative Cost and Schedule Comparison (Real-Year Dollars in Billions)

ing allowances, reserves, and confidence factors used for specific functions, and the rationale for costing assumptions. This documentation and candor gave us confidence that the Redesign Team's estimates had been prepared in an unbiased and realistic manner and provided our subcommittee with a sound basis for the assessments presented in this report. Figure 1 compares the "to go" costs, developed by NASA, of each option at reasonably comparable stages of development.

Major findings in the cost area are:

- Three viable design options were developed, each of which could be executed at a significant cost savings relative to Space Station Freedom. The cost savings arise primarily from management restructuring.
- The ultimate cost of a space station and its operations will be minimized only if Congress and

the Administration make a firm commitment to the program and provide stable funding.

- The generally understood costs of Space Station Freedom have grown substantially over time and are well in excess of those of the redesign options. The costs of Space Station Freedom and the redesign options are compared in this report on as consistent a basis as possible.

- None of the fully implemented phases of the three station redesign options meets the cost targets provided by the Administration of $5 billion, $7 billion, and $9 billion for Fiscal Year 1994 through Fiscal Year 1998, nor does any option meet the annual funding target while simultaneously achieving the schedule milestones desired. All options, however, do represent major cost savings relative to Space Station Freedom.

International Partners. The international partners' modules are not accommodated at the target funding levels. These modules can be accommodated in later phases of each option. The Canadian robotic servicing system is not fully accommodated in either Option A or Option C.

- The Advisory Committee is concerned about the growing perception of the U.S. as an unreliable partner in scientific pursuits, as well as the potential loss of capability provided by international investment and technology.

- The international partners express strong reservations about Option C based on its relative lack of maturity and programmatic uncertainties. The addition of international modules will no longer lead to the creation of a space station with greater capabilities.

Risk. The objective assessment of risk to human life and to the long-term operation of the space station must be a major element in decision making. Determining factors include the amount of required extravehicular activity by astronauts, the extent of protection against space debris, the availability of an assured crew return vehicle, and the need for alternative launch vehicle access to the space station. The Committee's assessment of the redesign options includes such considerations.

- An assured crew return capability must be provided, but was not accounted for in previous cost estimates for Space Station Freedom.

- Development risk (i.e., the probability of roadblocks and delays in the development of design, construction, and operation of a space station) is also an important consideration and has been assessed to a limited extent by the Advisory Committee. Development risk is affected not only by the complexity of assembly tasks evidenced by the amount of on-orbit assembly required, but also by such factors as the maturity of development of designs, equipment, and systems.

- All options, as currently presented, are dependent upon the space shuttle as the sole launch vehicle. This is undesirable from the perspective of programmatic risk, and carries a large "overhead" in the form of the shuttle's own mass of 200,000 pounds when launching

station components of up to 30,000 pounds per flight. This should be ameliorated by using an alternative expendable launch vehicle, such as the Russian Proton, European Ariane V, or U.S. Titan IV for lifting the heaviest elements.

Management. The level of cost reduction will be determined primarily by the extent of implementation of major structural changes in the management and organization of the program within both NASA and the civilian contractors. This will require great resolve on the part of NASA and the Administration.

- The NASA Administrator must be empowered to apply lean management and assign the appropriate skill base to the tasks at hand.
- Redundancies and overlapping responsibilities such as in the existing Space Station Freedom management structure must be eliminated. Management layers must be reduced, and program authority and responsibility must reside in the Program Manager. The Center Directors' role must be to make the assets of their centers available to the program, not one of programmatic control.
- A reduction of at least 30 percent in total civil service and contractor employees assigned to the Space Station Program should be implemented following principles of lean management to gain efficiency and effectiveness.
- The current cost projections for the options include significant savings achieved by restructured management, but more could be attained by further organizational changes.

Acquisition. A single prime contractor, preferably selected from among the current major prime contractors for Space Station Freedom, should be responsible for total system integration, including cost, schedule, and performance.

INTRODUCTION

The Space Station Program was initiated in 1984 to provide for permanent human presence in an orbiting laboratory. This program evolved into Space Station Freedom, later identified as a component to facilitate a return of astronauts to the Moon, followed by the exploration of Mars.

In March of 1993 the Clinton Administration directed NASA to undertake an intense effort to redesign the space station at a substantial cost savings relative to Space Station Freedom. This task was undertaken by the Station Redesign Team, consisting of 45 NASA employees and 10 representatives of the international partners. Numerous candidate station concepts were submitted by NASA Centers, industry, the Space Station Freedom Program Office, the international partners, and individuals. From these submissions, the Redesign Team narrowed the field to three basic design options for detailed study: Option A, a modular buildup; Option B, derived from Space Station Freedom; and Option C, a single-launch core station.

The Advisory Committee on the Redesign of the Space Station was established in March 1993 to provide an independent assessment of the advantages and disadvantages of the redesign options. Representatives of the international partners were also asked to serve as *ex officio* members of the Advisory Committee.

The Advisory Committee's charter stipulated that it should assess at least three design options for the new program that could:

- Support long-duration research in materials and life sciences, but not necessarily permanently manned.
- Achieve initial on-orbit research capability by 1997 or earlier, with U.S. development and assembly complete by 1998.
- Maintain opportunities for partnership with international partners and consider additional opportunities for international cooperation. Consider opportunities for Russian cooperation and/or use of Russian capabilities.
- Be configured for significantly lower cost of operations (e.g., annual operations costs shall be significantly reduced below existing estimates and within the constraints of the budget).
- Greatly reduce on-orbit assembly and checkout, including major reductions in required extravehicular activity and the potential for use of expendable launch vehicles.
- Implement a simplified and effective program management structure, including a transition plan for organizational and contract changes.
- Provide adequate budget reserves.
- Plan for a shorter on-orbit lifetime (e.g., 10 years extendable to 15 years).

This report describes the results of the Committee's work. The discussions that follow first describe the mission that the Administration has articulated for the Space Station Program and the scientific and technical characteristics that a redesigned station must possess to fulfill those objectives. This is followed by a description of recommended management, operations, and acquisition strategies for the redesigned program. The next sec-

tion, "Assessment of the Options," presents the Committee's assessment of the redesign options against five criteria: technical capabilities, research capabilities, schedule, cost, and risk. A section on general mission risk is also included. The report then provides an assessment of the options by the international partners, and a review of how the Russian space program could contribute to an international space station.

Significant risk is inherent in complex undertakings, especially in the hazardous environment of outer space. This challenging frontier and perhaps progress itself cannot be undertaken free of risk, yet we believe that it is important to straightforwardly review the factors that can lead to systems failures or danger to persons in order to facilitate decisions and actions that minimize them. Therefore, in addition to assessing these matters in our review of the redesign options, we included the section on General Mission Risk, a broad discussion of these factors associated with complex space missions.

MISSION AND REQUIREMENTS

To effectively assess a redesigned space station, the Advisory Committee asked Dr. John H. Gibbons, the Director of the Office of Science and Technology Policy, to provide an understanding of the Administration's first-level objectives for the space station. Although Dr. Gibbons replied that the Administration was still formulating its plans for the civil space program, he did indicate that the Administration intended "to ensure that all the resources dedicated to the civilian space program are well-managed and focused on issues that are critical to the nation." In their view, the space program should create new knowledge, contribute to the U.S. economy, provide opportunities for international cooperation, and motivate young people to take an interest in mathematics and science.

Regarding the space station, Dr. Gibbons stated that the Administration believed that the program should accomplish the following objectives:

- Create the capability to perform significant long-duration space research in materials and life sciences;
- Develop the technology and engineering skills necessary to build and operate advanced human and autonomous space systems;
- Encourage international cooperation in science and technology;
- Provide opportunity for new users, particularly industry users, to conduct experiments on new, commercially relevant products and processes;
- Acquire new knowledge regarding the feasibility and desirability of conducting human scientific, commercial, and exploration activities.

If a space station is developed, its utilization will be in the national interest. A number of advisory bodies have identified and discussed those discipline areas that can best be served by research conducted in a laboratory in space. A space station will serve as a national and international laboratory for activities including: (1) studies of the effects on humans of long-term presence in space, including their health and capabilities; (2) engineering research and technology development that require experimentation in space in order to enable or improve appropriate future human and robotic space activities; and (3) scientific studies of the uses and effects of microgravity on materials sciences, fluid behavior, combustion, and other phenomena and processes. It is expected that there will be unanticipated opportunities and adjustments as a station-based research program proceeds.

For example, experiments in life sciences may contribute to new understanding of the circulatory system, the nervous system, bone and muscle metabolism, and lead to new medical devices and sensors. In material sciences, research will contribute fundamental knowledge important to the development of advanced materials.

A space station will only serve its research purposes if there is a Research Manager who has line authority. The Research Manager must have a stable and protected budget so that the science initiatives and laboratory resources of the user community are protected.

Many of the science returns that will result from research on a space station will come from elucidating the underlying mechanism of space adaptation. Reaching this goal will require, in some instances, missions of extended duration (6 months or longer) and a minimum crew complement of four or more.

Some research involving microgravity payloads may require frequent human tending, and yet other microgravity projects may be designated for extended periods of primarily ground-tended operations. Program planning, time sharing, and ease of access would maximize the utility and efficiency of a space laboratory.

"User group" issues such as time in orbit, number of experiment racks, power, crew availability, and microgravity levels have been specified in past reports. For example, an overall space station environment of 14.7 psi, 21 percent oxygen, carbon dioxide levels (nominal operations) of 0.3 percent, and zero g and one g, are required for life sciences research. The requirements for specialized equipment such as centrifuges and furnaces will depend strongly upon the research projects that are prioritized for pursuit. The prioritization process that determines the investigations for flight will likely be iterative and include as ranking criteria the subjects to be pursued, the organizations (government, academic, and commercial entities as well as international partners) responsible for the investigations, and the resources available. The financial resource limitations in any station program should motivate the design and development of innovative equipment and technology.

Among the possible user groups for a space station, the commercial sector is the most difficult to assess. Commercial uses of a laboratory in space can take many forms, including collaborations with NASA-sponsored, university-based organizations, such as the present Centers for Commercial Development of Space. Under this arrangement, funds from NASA are expected to be supplemented by commercial firms, and/or by "in kind" contributions. Research can also be carried out independently of the commercial development centers, with the company interfacing directly with NASA through a Joint Endeavor Agreement. Other types of commercial space research range from those where NASA provides partial to total funding, to those activities that involve no exchange of funds.

If a space laboratory is a long-term research investment, then how are commercial interests best coupled to it? The answer is not easy, and is often couched in terms of political assessments and views of how government should best be organized to interact with and foster industrial/commercial policy. Often it is said that industry tends to be short-term oriented (research horizons of perhaps 5 years; possibly 10 in some instances) and that therefore government (NASA in this case) needs to pursue the longer-term research that would be provided by a space laboratory. This is largely the situation at present where in the case of the Centers for Commercial Development of Space, research that might have future long-term commercial possibilities is funded by NASA. This requires good foresight on the part of NASA and its university-based commercial centers to anticipate the needs in non-aerospace commerce some 10 or more years in the future. Such a long-term assessment is difficult enough for industry in planning its own long-term research agenda and strategies.

A review of the literature on the commercial opportunities available with the space shuttle and those proposed for a

space station shows that many potential opportunities were oversold. Additionally, there has been relatively little involvement by major, non-aerospace corporate laboratories. Although there has been somewhat intense activity for a few years by a handful of companies, the interest has largely waned in each case. Reasons for the declining interest include the development of more competitive ground-based processes, the lack of assured and frequent access to space, and fluctuations in the business climate that affect the levels and directions of research support. The most recent intense, non-pharmacological research conducted from the middeck lockers of the space shuttle was terminated largely in response to changes in the economic business climate and a reorientation of the company's research spending.

Proposed space station research should continue to be reviewed and prioritized externally and internally, as is presently done for space science experiments by groups such as the National Research Council and the NASA Advisory Council. Only those research projects that can best make use of the unique attributes of a space laboratory should be considered for ultimate flight. An important part of the prioritization process should include an assessment of the competitive means of accomplishing the research objectives, whether these means are space- or ground-based, or whether they are robotic or human-tended. In most cases, only those research topics that survive such competitive evaluations would be retained for further consideration for flight on the space station.

Because of the unique opportunities that a space station can provide for certain research areas, and because of the limitations that will exist for funding and other resources, the development of priorities should be viewed from a positive perspective. Such a process will ensure that only the most appropriate and very best research is selected for flight.

GENERAL MISSION CONSIDERATIONS

Launch Vehicle Considerations

The current space station is based on exclusive use of the space shuttle for lifting its components and crew to Earth orbit, as are Options A and B. Although Option C uses a new launch vehicle for its large initial load, it depends on the shuttle to carry the Japanese and European modules and other heavy outfitting payloads. All three options plan 50 shuttle flights over 10 years to supply and refurbish the station. This exclusive dependence on shuttle is both unnecessary and undesirable.

There are several problems with a "shuttle only" policy, and they are apparent in Figure 2. The first problem is basic lift capability. The shuttle will launch about 30,000 pounds of useful station payload into a 28.8° orbit. The pressurized laboratory modules are significantly heavier when fully fitted, and so are a number of assembly payloads. A second problem is the high probability that the shuttle could be grounded again during the assembly or operational phase of the station program. The third problem with shuttle is that it has increasing difficulty supporting heavy launches into the 51.6° orbit, which permits alternative access to the space station (see station orbit selection section).

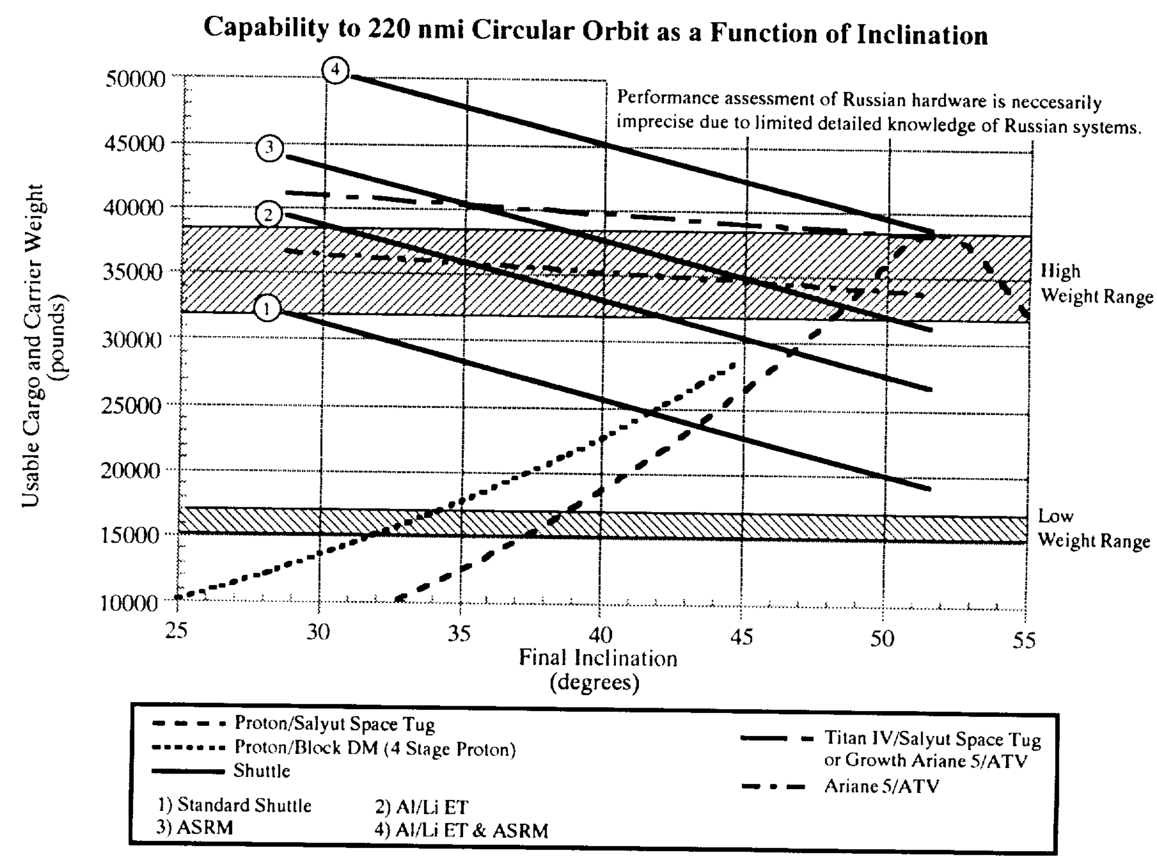


Figure 2. Shuttle, Titan IV, Ariane V, and Proton Capabilities

This problem is displayed in Figure 2. Shuttle capability falls off rapidly with increasing inclination, whereas the capabilities of unmanned rockets like Titan and Ariane do not. The reason is straightforward. Each time we launch a 30,000 pound payload with the shuttle, we must put a 200,000 pound vehicle into orbit. When the inclination is changed, the small associated performance penalty for this large vehicle must all come out of the useful payload. In business terms: a large fixed overhead rapidly eliminates the profit. This is not the case with the Titan and Ariane, which do not seek to recover and reuse the launch hardware. The Russian Proton vehicle can lift significant payloads to the 51.6° orbit, but it is seriously handicapped for lower inclinations by range safety and orbital mechanics considerations.

The present shuttle struggles to place heavy payloads into Earth orbit even at the 28.8° inclination. In order to accommodate heavy modules, experiment racks must be unloaded. An alternative is to develop the lightweight aluminum-lithium shuttle external tank. Both unloading and the lightweight tank are clearly required to lift the heavy payloads to the higher inclination orbit in the three options.

The important message of Figure 2 is that it is not necessary to upgrade the shuttle if we open up the launch vehicle role. The large unmanned rockets can easily lift the heavy payloads to the station's orbit. The large payloads can also be carried into a 51.6° orbit by the Russian Proton rocket and its various upper stages, some of which have built-in docking systems. By opening up the launch vehicle opportunity to unmanned vehicles, we also achieve much needed launch diversity. This would provide protection against long groundings of one particular vehicle. A mixed fleet of shuttle and expendable launch vehicles is therefore very desirable.

Assured multiple launch access should be made a firm requirement for the space station.

Assured Crew Return Vehicle

All three options have a firm requirement for an assured crew return capability—a space "lifeboat" or "parachute." This is required to evacuate crew members in case of illness or accident, or if the station itself stops working because of equipment malfunctions or a catastrophic impact or if there is an extended shuttle stand down. When the shuttle is docked at the station, it provides the capability to "bail out." However, the shuttle is only present a small fraction of the time. A separate assured crew return vehicle carried on the station at all times is thus required. No such vehicle is being developed in the U.S.

Fortunately, there is a solution to this problem. The Russians have developed the Soyuz spacecraft, which can easily be attached to the various station configurations, as an assured crew return vehicle. The only question is how to transport the Soyuz capsules to the station and how to provide a suitable landing area when they return. The Soyuz capsules must be returned every year or two for refurbishment and returned to the station. If the station inclination is 28.8°, the shuttle must be refit to carry a modified Soyuz to orbit in the cargo bay. The shuttle would also return the Soyuz to Earth for refurbishing. When used as an assured crew return vehicle, the Soyuz would land in water, or on undesirable terrain. In the event of such emergency use it is unlikely that we could deploy the naval forces of the scale used in Apollo on short notice.

An assured crew return vehicle is a firm requirement for space station, and Soyuz is the only viable contender.

Station Orbit Selection

Russian rockets and the Soyuz spacecraft are the only man-rated systems now available for dual human access and assured crew return. To avail ourselves of this proven capability, we should change the station's inclination to 51.6° so that its orbit is achievable from the principal Russian launch site in Kazakhstan. The clear advantage of the higher inclination is:

- The entire stable of previously developed Russian launch vehicles is available—as needed. In particular, the Soyuz can be used for alternative crew access, while the Progress cargo vehicle, which the Russians have often used to resupply their own stations, will also be available.
- The Soyuz can be launched as an assured crew return vehicle on its own tested rocket, rather than going through a costly adaptation to shuttle.
- If the Soyuz is needed to return astronauts suddenly, it will have most of the U.S. and Kazakhstan in which to make its normal land recovery.

On the other hand, there is a price to pay for these advantages. The shuttle cannot put as much payload into the higher orbits as it can into the 28.8° orbit as illustrated in Figure 3. The offsetting actions that can reduce or eliminate this loss are displayed in the other columns. For instance, if a new aluminum-lithium external tank is built for shuttle, its payload would be improved by 7,500 pounds. This leads to the *net* payload penalties shown in the second column. The aluminum-lithium tank development would cost less than a single shuttle flight. In addition, the Shuttle Program Manager carries a 3,500 pound reserve, most of which can now be prudently converted to useful payload. Assuming 2,000 pounds of the reserve for payload lift gives the results in the third column. Finally, one can assemble the heaviest station components at 175 miles rather than 220 miles as now planned. The completed assembly would then be propelled up to the final altitude by the station's existing propulsion system and the spent fuel replaced on a later flight. This saves another 4,500 pounds for each shuttle flight, leading to the positive margin shown in the last column.

NASA should proceed with the development of the aluminum-lithium lightweight tank.

The Russians now routinely launch from Baikonur, which has a latitude of 45.6°, to an orbit inclination of 51.6° to avoid dropping the main stage or an aborted spacecraft in China or Mongolia. They pay a payload penalty to do so. This orbit inclination is satisfactory for the Russian rockets, supply vehicles and return capsules.

We recommend an inclination of 51.6°. The choice of this orbit would also make the space station accessible to Russian launches, and to vehicles launched from Japanese and Chinese sites.

Communications

The present space station design and its three alternatives now depend exclusively on NASA's own Tracking and Data Relay Satellite System (TDRSS) communication satellites for all of their communication services. It is dangerous and unnecessary

Orbit Inclination	Shuttle Payload Reduction	With New Aluminum-Lithium (Al-Li) Tank	Shuttle Reserve Release Plus New Tank	Assembly at 175 Nautical Miles Plus Reserve Release and New Tank
28.8°	Nominal	+7,500 lb	+9,500	+14,000
51.6°	-11,500	-4,000	-2,000	+2,500

Figure 3. Payload Increases and Decreases Relative to Nominal 28.8° Orbit Inclination Launching

to do so. There are almost 100 communications satellites in the same synchronous orbit where TDRSS resides. All of them provide wide-band communication services. In addition, our international partners maintain data relay satellites on orbit. Using such spacecraft, over 10,000 ships at sea now have two-way satellite service. Television is received directly by millions of households with small backyard antennas. Corporate locations and chain stores are increasingly linked together by small on-premise satellite terminals. It is a simple matter to add a second type of satellite dish to the station configuration. If we do so, we can establish important redundancy for the communication links that are vital to crew safety and station operations. Scientific work would also benefit from alternate communication routes.

We recommend an alternate communication pathway be included in the space station.

Subsystem Comparison

It is instructive to compare the three design options with respect to their subsystems: life support, power, communication, etc. For these systems, there is no appreciable difference in the cost to go between the options, except for the Data Management System.

The option designer had three choices: select space shuttle derived systems, or select systems from other space programs. The only way to save cost at the subsystem level is to delete capability. Since many subsystem capabilities are locked in by fundamental requirements and safety considerations, savings are difficult to achieve.

The data management systems for the three options are quite different—and so are their costs. Because they represent an important distinguishing feature, the data management system capability will be discussed for each option in the section titled "Technical Capability Comparison."

MANAGEMENT, OPERATIONS, AND ACQUISITION

Management and Operations

The current management approach for the Space Station Freedom Program is not working at maximum efficiency, and the fix to this problem will require leadership. A streamlined organization will produce significant program savings and perhaps more importantly, a flexible organization capable of firm, high-quality, and expeditious decision-making with clear lines of authority and responsibility. Early detection of and response to problems, cost containment, and adherence to schedules should also be expected. The principles articulated below represent the *minimum* changes in management that will be required for the Space Station Program to be successful.

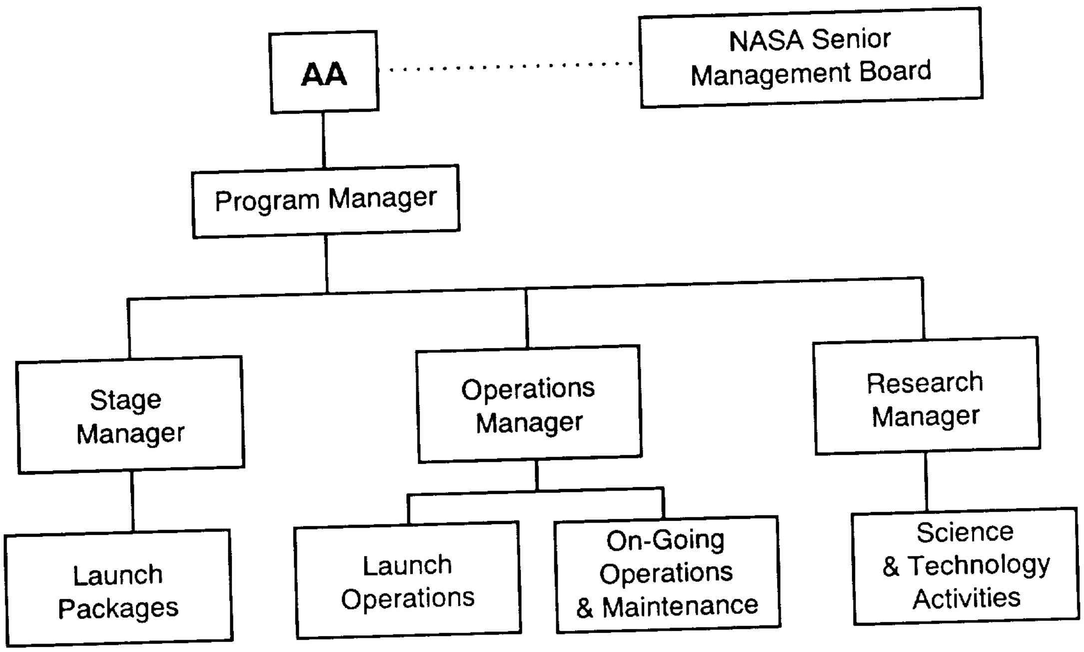
For all options, modern, lean management principles will need to be embraced by both the space station's management and operations organizations. With effective leadership, this new management and oversight structure will be effective in delivering NASA's objectives, in contrast to the many-layered, interlaced organization presently in place.

The revised management structure must have clearly defined lines of authority and responsibility for all positions, including the management provided by outside contractors. Particular attention needs to be given to the program office Associate Administrator, the Space Station Program Manager, Stage Managers, and other management staff. The Redesign Team recommended three layers of management between the station program manager and the teams responsible for the launch packages. The Committee believes this could be reduced to two layers as shown in Figure 4.

A space station provides a research capability for those activities that require the characteristics of the space environment for their pursuit. As such, the research to be carried out must be viewed as an integral part of the station program management from the very beginning, and throughout the design, construction, and operations phases. Indeed, the operations phase, which exists explicitly to enable research, continues throughout the life of the station. Therefore, in view of the research purposes of the station, we believe that the "Research Manager" should be a line activity rather than a staff function. Ultimately, utilization activities should be considered along with hardware development and operational protocols. As a line function, the manager will ensure that all aspects of the research—from planning and selection to flight and data analysis—are given the attention and support that are necessary to ensure mission success. This proposed organization also gives the Space Station Program Manager the responsibility to solve tradeoffs during the development and operations phases and provides for "life cycle oversight" rather than isolated "event" or "phase" management.

The Committee recommends that NASA maintain an independent oversight and authority function to validate all safety issues during the development and operations phases. However, independent verification and validation of software should be a contractor requirement.

To avoid the "turf" battles of the past and to provide the high-level NASA acceptance of the new management structure, the role of the NASA Center Directors in the space station organization must be clearly defined. The role of each Director



NOTE: MANAGEMENT ROLES

- ***Associate Administrator:*** Assures that the Program Manager has the necessary resources to execute the program.
- ***Program Manager:*** Responsible and accountable for all aspects of program execution (performance, cost, schedule).
- ***Stage Manager:*** Responsible for the design, build, test, and integration of the various system components.
- ***Operations Manager:*** Responsible for mission planning, mission execution, and logistical support.
- ***Research Manager:*** Responsible for utilization planning, experimental hardware design, and research execution.

Figure 4. Recommended Space Station Program Organization Structure

should not be to provide the management for the overall program, but to provide the resources (personnel and facilities) necessary for the success of the program. The single most important responsibility of the Center Directors is to provide the best-qualified personnel for the project in a timely manner. This necessitates that the Center Directors be supportive of the streamlined management and operations organization, and that competition and overlap between Centers are eliminated. This revised role for Centers is critical to the success of the recommended program, and the NASA Administrator must take whatever action is necessary to assure that the Directors support and fully embrace the streamlined structure. The Redesign Team's recommendation of a NASA Headquarters level space station "Board of Directors" includes the Directors as members. This is a good vehicle for providing the Center Directors with both an advisory role and a continuing current source of information on what resources they need to provide to the station program. In addition, the "Board of Directors" should include the full partici-

pation of the international partners to ensure that policy issues affecting them are worked out at this level.

During the development and operations phases, there should be close integration between the Shuttle and the Space Station Program Offices. This cooperation is essential for the success of the redesign, and would provide savings in excess of those projected in this report. The Committee, however, is uncomfortable with the Redesign Team's recommendation to merge the programs if Option C is chosen. The track record of the Space Shuttle Program would suggest that the management and operations principles outlined above should be employed for any option chosen. The Space Station Program Manager, who has both the responsibility and authority to optimize the overall station development and utilization, must not be burdened with the overall shuttle issues, even though the two programs are intertwined.

The principles outlined above are generally in agreement with the Redesign Team's recommendations. However, the Committee believes that the Team's estimate of a $300 million per year savings due to these management and operations changes is a minimum gain. Their report indicates that NASA has 2,300 full-time equivalent civil servants "helping" the contractor with over 500 engineering working groups, panels, and boards. This complexity causes the contractors to have a corresponding network to respond to the government oversight and paperwork analysis. The Redesign Team believes that "lean" management will reduce oversight requirements by 80 percent and reduce the contractor "paperwork" cadre costs by 10 to 20 percent, and that NASA managers project a reduction of 25 to 50 percent of the civil servants needed to perform their functions. The "entitlement" from these improvements could realize a savings of up to the $700 million to $1 billion range per year for NASA overall.

NASA should staff the program with the best people with the appropriate skills regardless of whether they are civil servants or contractor personnel. Without the full and enthusiastic support of NASA senior management, it will be very difficult to effect the magnitude of suggested change that is required. As a functioning Senior Management Team, the Center Directors and the Associate Administrators have the power to define the roles and missions of the Centers and to distribute work in a way that maximizes program performance while still satisfying geopolitical realities and constraints. This requires an atmosphere of cooperation and trust and willingness to sacrifice for the larger good of the Agency. The Redesign Team's recommendations for the organization of Integrated Product Teams will deliver the cost savings. In order to ensure maximum efficiency, the Product Teams must include representation from all necessary disciplines and the international partners.

The Advisory Committee defines operations as the "single program cost account that pays all program cost from the time that flight hardware is delivered in any form to the Kennedy Space Center for pre-launch processing." However, the space station program is a continuum, as illustrated in Figure 5 where the development phase moves smoothly into the utilization phase. As timelines are met, development costs will go down, and operation costs will increase. As the station begins to function, operation costs should level off, and utilization costs associated with the sciences and technology activities should grow. Thus, the total program costs will peak before "first flight" and come to some equilibrium in the utilization phase.

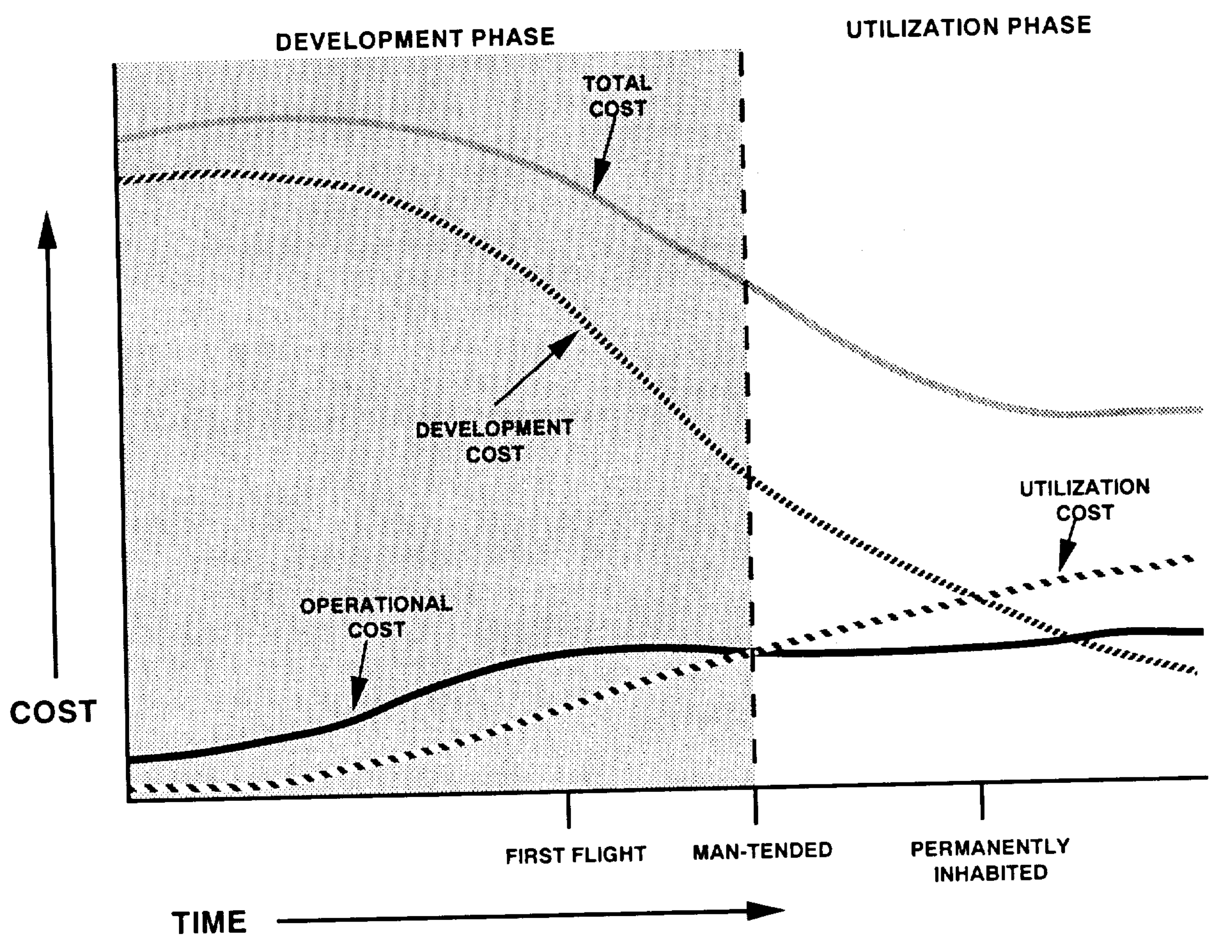


Figure 5. Transition from Development to Utilization Phase

The station should be viewed as an orbital laboratory. Therefore, the development costs will never fall to zero, and the utilization costs will reflect the quality and type of science and technology activities chosen worthy of funding. Thus, the Committee believes that the management structure outlined above is applicable for the entire life-cycle of the station. Additional comments on operations are shown below.

- The first priority of the operations management is "to maintain the health and safety of the space station crew and the integrity of the space station."
- NASA has the fundamental capabilities necessary to execute the operations program; however, the station's management structure must be streamlined.
- After safety, the priority of the operations management is to provide the station researchers with the most user-friendly, productive laboratory possible within appropriate budget restraints.

Acquisition Strategy

The Committee concurs with the Station Redesign Team's acquisition strategy of the selection of a single prime contractor with appropriate designated subcontrac-

tors. This will require the termination of certain existing contracts and the re-orientation of others.

The station program will be best served (in timing and cost) by selecting a single prime contractor. This contractor should be selected from one of the current major primes, with directed subcontractors. The prime would be responsible for total system integration, including cost, schedule, and performance.

It is noteworthy that in visits to participating contractors, there was a strong willingness to work together and a preference expressed that one contractor be selected as Prime/Integrator and that the other contractors work as subcontractors to the prime.

Options A, B, and C require strong centralized program management rather than diffuse involvement by three centers and three prime contractors, which has been almost universally identified as the major management and acquisition issue to date. A single prime contractor would facilitate decisive action, reduce cost and delay, and improve communication among space station participants.

The timing and execution of the termination action are critical to programmatic success. Clearly, a program of the dollar magnitude and technical complexity of a space station, which is significantly restructured, must be carefully planned and executed. The Station Redesign Team's approach is credible, and it provides appropriate guidance for the transition to the redesigned space station.

The three prime contracts and many of the subcontracts are cost plus award fee. This approach should be continued with an award fee that is made up of two parts: a short-term part for maintaining momentum of the planned program; and a long-term portion to reward final satisfactory completion of significant station program objectives. The short-term award should be on a 6-month review of agreed-upon progress toward program events. This incentive will support the ongoing plan to achieve the long-term objectives. The long-term award should be based on the completion of major program objectives as defined by specific design parameters, performance, schedule, and cost. To maintain the focus and pace of the program, the Space Station Program Manager must be the award-fee official.

The Committee endorses the Station Redesign Team's recommendation of a dedicated transition and implementation team to take ownership of the Space Station Program and the necessary acquisition issues associated with the redesign. This team should be the restructured management team outlined earlier in this section.

DESCRIPTION OF OPTIONS

Three station redesigns were developed; they are termed Options A, B, and C. Options A and B are largely derivative of Space Station Freedom. Both grow over time in a modular fashion through several phases of capability, as shown in Figure 6. Option C does not grow in a modular fashion; it has a large pressurized cylindrical habitation and experimentation module that is lofted into orbit in a single launch. Therefore, its first phase is U.S. permanent human capability. Seven additional assembly flights are required to achieve permanent human capability, which includes the international modules.

Option A

Option A introduces new designs, as well as modifications and rearrangements of Space Station Freedom elements. It resembles a scaled-down version of Freedom, with solar arrays stretching out from a central truss structure (Figure 7). The Station Redesign Team has formulated two similar versions of Option A. The first, termed Option A-1, incorporates Bus-1, a Department of Defense propulsion boost and attitude control system built by Lockheed Missiles and Space Company. Option A-2 is essentially identical to A-1 in all aspects except it uses the Space Station Freedom propulsion modules instead of the Bus-1.

Option A draws heavily from Space Station Freedom elements. Starting with the Freedom base, the Station Redesign Team deleted hardware, made simplifications, and applied cost-effective substitutions from other programs. For example, the design deletes some truss sections, uses a common core/laboratory module rather than a node plus laboratory, simplifies the electrical power and data management systems, and uses a smaller airlock. The shuttle orbiter provides human habitability support in early phases.

The modular approach for this option incorporates four buildup phases. The first phase is the Power Station: an orbiting source of electrical power to which a shuttle could dock. A crew of five would live and conduct experiments in the shuttle for nearly a month. The Power

OPTION A	OPTION B	OPTION C
Power Station	Power Station	
Human-Tended Capability	Human-Tended Capability	
International Human-Tended Capability	International Human-Tended Capability	
Permanent Human Capability	Permanent Human Capability	U.S. Permanent Human Presence Capability Permanent Human Capability

* Option C has an earlier U.S. Permanent Human Capability
Note: Permanent Human Capability includes international accommodation

Figure 6. Space Station Redesign Option Capability Phases

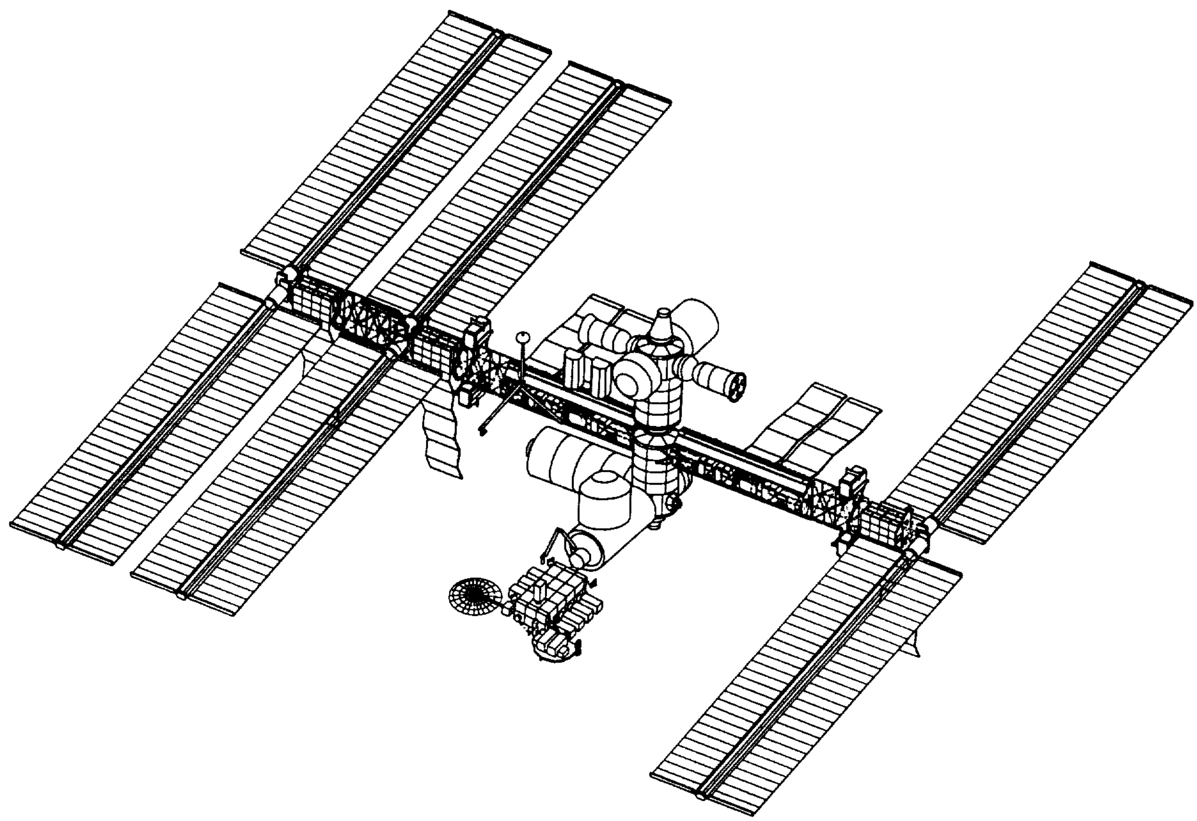


Figure 7. Option A – Permanent Human Capability

Station provides 23 kW of power through one set of solar arrays and requires three assembly flights.

During the second phase, Human-Tended Capability, a common core/laboratory module is added and provides capability for 30-day crew stays. This phase provides 23 kW of power and requires four assembly flights.

International Human-Tended Capability is the third phase, which adds a second set of solar arrays to provide 46 kW of power and requires nine assembly flights. This phase completes the addition of all the international modules.

Permanent Human Capability is the fourth phase. A third set of solar arrays increases power to 57 kW. A total of 13 assembly flights ultimately add an airlock, closet module, and two Russian Soyuz spacecraft that serve as assured crew return vehicles.

Option B

Option B (Figure 8) is a direct evolution of the current Space Station Freedom design with a modified data management system and communications and tracking systems and minor modifications to the environmental control and life support system and the thermal control system.

Option B features four buildup phases. The first phase is the Power Station, which is achieved in two assembly flights. This phase provides up to 23 kW of power to the shuttle for running Spacelab experiments and extending stay times.

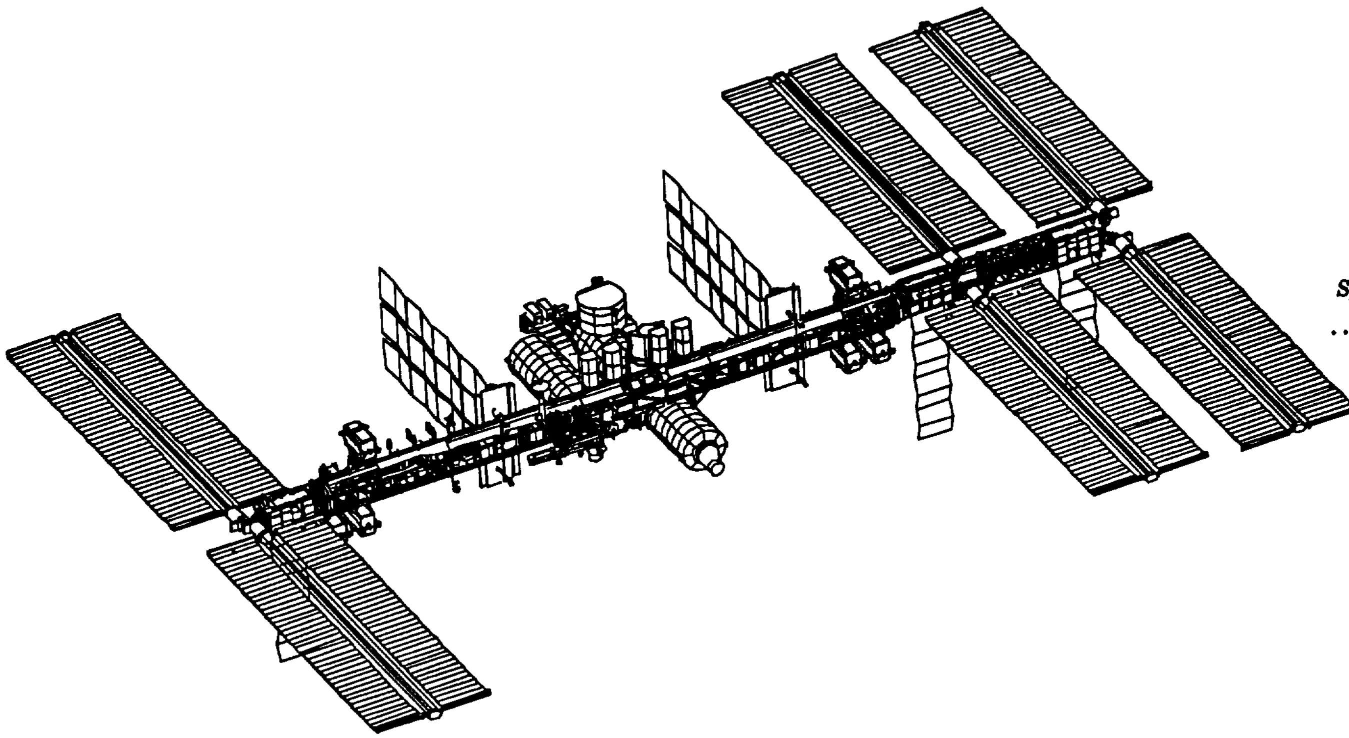


Figure 8. Option B – Permanent Human Capability

The second phase, Human-Tended Capability, features a fully operational node and U.S. laboratory, the mobile servicing system, the EVA airlock, and two additional truss segments. Human-Tended Capability can support payload operations with or without the shuttle. The configuration also allows docking of two shuttles simultaneously, which can extend crew time on orbit.

The third phase is International Human-Tended Capability. At its completion, this phase features a full complement of U.S. and international partner laboratories and elements. The configuration supports crew science experiment operations during shuttle visits, and untended science between shuttle missions.

The final assembly phase adds the habitation module and two Soyuz assured crew return vehicles to establish Permanent Human Capability, which supports a crew of four.

Option C

Option C (Figure 9) is a hybrid station which utilizes systems and infrastructure from the Space Shuttle Program and Space Station Freedom. Option C is an integrated system with a launch configuration that includes the single core station module, the aft fuselage from an orbiter, space shuttle main engines, a transition section for adapting the aft fuselage geometry to the core module, and aerodynamic fairings (e.g., shroud, nose cone) mated with the basic space shuttle external tank and standard solid rocket boosters.

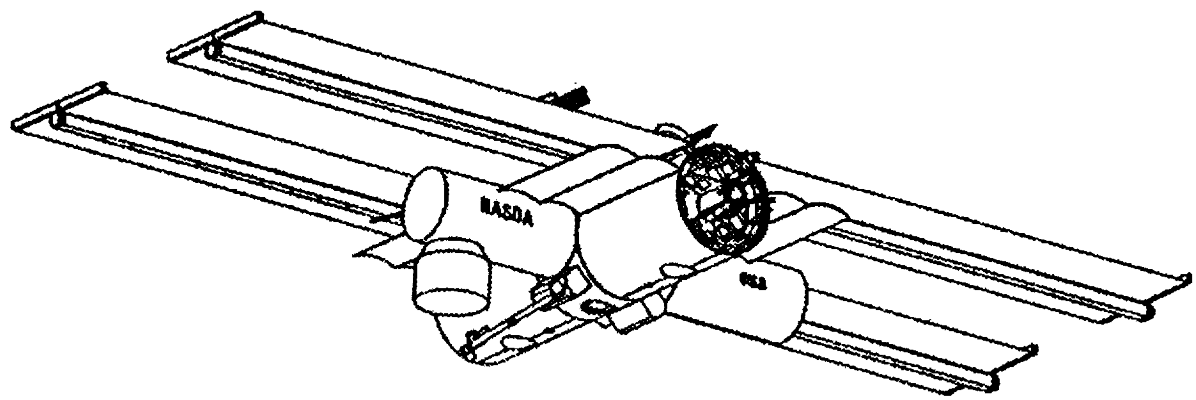


Figure 9. Option C – Permanent Human Capability

The components of Option C are extensively integrated and verified prior to launch. After one shuttle visit, Option C has the capability of a human-tended station. A second shuttle flight establishes U.S. Permanent Human Capability. Although humans can permanently inhabit the station, the international laboratories are not present. When the international modules are brought up, Permanent Human Capability is established. The last phase is the incorporation of an auxiliary power module, which completes the station about a year after the first launch.

The distinctions of Option C are the phasing of capability and the reliance on many shuttle-derived systems. During launch and ascent, the vehicle must function as a part of the launch system. This drives the design to include many of the shuttle's systems for attitude control, propulsion, communications, and data management. Once in orbit, these systems are augmented by the power, crew health, and environmental control systems derived from Space Station Freedom and the space shuttle. The design of Option C mixes Freedom and shuttle systems as appropriate, in an effort to minimize development cost and risk of both the launch and orbital phases. However, since the Orbiter Columbia must be decommissioned to provide the aft fuselage for this option, NASA's shuttle fleet will be reduced to three.

Option C can quickly support permanent human occupancy by a crew of four. The 92-foot-long, 23-foot diameter module is divided into seven decks, offering the most pressurized volume of any options.

ASSESSMENT OF THE OPTIONS

This section discusses the Advisory Committee's assessment results. It is not possible to individually assess the many elements of a system as complex as a space station. Therefore, the Committee developed a high-level set of evaluation criteria against which each of the options was measured. The evaluation criteria reflect the consideration of several factors: the objectives articulated by the Administration, scientific research and technical capabilities requirements as guided by external advisory groups, and ability to meet cost, schedule, and other guidelines that formed the framework of the redesign effort.

Comparing the options requires both broad qualitative and detailed quantitative perspectives. The several phases within each option compose a very extensive set when all possibilities are considered. In the qualitative approach, the options and their constituent phases are differentiated by how well they support the five fundamental and principal objectives of the space station, as derived from the Office of Science and Technology Policy guidance letter of April 30, 1993 (Figure 10). Some of these purposes intrinsically conflict with others, so none of the options (or Space Station Freedom) is perfect in satisfying all requirements.

Create the capability to perform significant long-duration space research in materials and life sciences.
Develop the technology and engineering skills for building and operating advanced human and autonomous space systems.
Encourage international cooperation in science and technology.
Provide opportunity for new users, particularly industry users, to conduct experiments on new, commercially relevant products and processes.
Acquire new knowledge regarding the feasibility and desirability of conducting human scientific, commercial and exploitation activities.

Figure 10. Office of Science and Technology Policy Space Station Program Objectives

In the remainder of this section, the Committee presents its assessment of the redesign options against the following evaluation criteria: technical capabilities, research capabilities, schedule, cost, and risk. The previous section included brief descriptions of the three options, which provide the framework for the assessment information. This section then concludes with a summary of assessment results.

Technical Capability Comparison

This section compares the three options in terms of fundamental technical capabilities. A detailed matrix of space station capabilities is provided in Appendix D.

Our first recommendation deals with the power station configuration. The Station Redesign Team report includes a power station configuration in Options A and B. Because of limitations on crew time on orbit, this configuration would be of little utility. The benefit of the power station configuration as a stopping point does not support the cost of its development.

The power station should not be considered as a configuration stopping point in Options A and B, and the Advisory Committee has not evaluated it further.

Option A

This option is an engineering simplification of the baseline Space Station Freedom. The elimination of the two U.S. nodes has simplified the pressurized volumes. Many of the subsystems, including data management, software, electrical power, thermal systems, and pressurized modules have also been simplified.

In particular, the data management system of Option A is a desirable simplification of the baseline Space Station Freedom system. It has replaced two data bus systems, one specially made for Freedom, with two identical standardized systems. The revised system has also replaced two distinct processors with one common standardized processor. The software design has eliminated many of the high-level software service functions intended to support research, but which are of uncertain actual value. Interfaces are largely preserved, and, where changed, have been simplified. Finally, the system eases integrated verification of the data management and other hardware subsystems. The downsizing of the Option A data management system, as compared with the baseline program, should be considered "right sizing." It has maintained much of the important capability, is based on reasonably up-to-date technology, and has reduced cost and much of the remaining development risk.

Two variants of Option A were proposed. A-1 includes the Bus-1, a derivative of a classified satellite program, which would supply propulsion and attitude control functions. A-2 uses Freedom baseline station- derived hardware for these functions. The discriminators between A-1 and A-2 are subtle. Both are technically feasible, and are not differentiated in the Committee's recommendations. Option A-1 and A-2 have the same assembly sequences and schedule. A-1 has inferior attitude control capability compared to A-2, but it is sufficient. The concept of integrating Bus-1 is somewhat immature. If Bus-1 were provided at no cost by the owner agency, then A-1 would have a very slight cost advantage over A-2; were this not the case then A-2 would have a $600M cost advantage. Option A-2 has only single fault tolerance during construction. A-1 has the advantage of fewer EVA hours required for maintenance and has multiple redundancy in attitude control functions during assembly. Both features factor in reducing operational risk. A-1 has poorer but acceptable performance, and lower operational risk. A-2 has slightly better performance, but greater operational risk.

The capabilities and benefits of Option A grow significantly through the four phases, and the additional cost to complete the later phases is relatively small. Human-tended capability represents a substantial fraction of the development cost of permanent human capability, but much less than 50 percent of its ultimate capability. The addition of the international modules represents little development cost to the U.S., and offers significant enhancements to the station's research capability. "Finishing" the port side of the station and habitation module mostly requires recurring equipment, which is much less expensive than the development cost already incurred. Thus, the cost/benefit ratio of Option A is least attractive at human-tended capability and most attractive at permanent human capability.

Option A is a fully capable space station. If it is selected, the Advisory Committee recommends completion of Option A through permanent human capability from a technical and cost / benefit perspective.

Option B

Option B is the design most closely derived from Space Station Freedom. Except for minor changes, the phasing of capabilities and subsystems is the same. This provides two advantages. The hardware is at a maturity level corresponding approximately to the Critical Design Review (i.e., mostly designed, with prototypes tested). Additionally, the baseline station is highly capable. Its design has evolved after years of engineering review and iteration with the research community.

The data management system of Option B has largely maintained the baseline of Space Station Freedom, which is an extremely complex, state-of-the-art system. It has two data bases, one fiber optic ring, and two levels of processors, distinct but with similar functionality. The software is extremely flexible, but costly. It arguably has too much capability for the currently perceived mission of the station, and presents significant schedule and cost risks in the development phase.

The cost benefit arguments made for Option A also apply to Option B. A great deal of the cost is incurred by the human-tended phase, with a smaller fraction of the benefit achieved. In terms of its system capability, Option B at permanent human presence has a highly capable and pervasive data system, with the ability of nearly autonomous function. As in Option A, the systems are capable of being monitored, and of evolution and growth. The robotics capability is highly developed in Option B, with the manipulator mounted on a mobile transporter. The attitude of Option B is always fixed with reference to the Earth, aiding observation and microgravity research.

In terms of capability, the disadvantages of Option B are the results of the larger number of EVA hours, which reduces productive crew time for research, and the smaller number of external payload attachment sites, due to the requirements for the mobile transporter of the robotic arm.

Option B, the closest derivative of the Space Station Freedom, is a complex and highly capable space station. It may, however, carry unnecessary system complexity in order to provide this capability.

In view of its reduced complexity, lower number of assembly flights, EVA assembly and maintenance requirements, earlier permanent human capability, and relative overall capability, Option A is preferred for a modular buildup station over Option B.

Option C

Option C is distinctive in concept from the baseline station and from Options A and B in that its capabilities accumulate in a different pattern. Option C has the largest inhabited volume and number of experiment racks. Because few of its systems are mounted on the exterior of the station, less EVA maintenance is required, and therefore 10 to 15 percent more crew time is available for research. Because of its diameter, Option C has the potential for a larger centrifuge for life science, although this is not included in the proposed program.

As a single core station, Option C does not evolve through phases. All basic systems are checked out prior to launch, and operating capability is realized when the astronauts arrive. Bringing on the international modules involves very little increase in U.S. cost. The addition of a power module is a several hundred mil-

lion dollar item and is part of the proposal. In view of the small additional costs, there is no compelling reason to consider stopping Option C before international permanent human capability.

Because of its shuttle systems heritage and single core approach, Option C has some capability limitations. It has restricted exterior space for attached payloads and has the least capable data management system. The data management system of Option C is understandably driven by the requirements of the launch phase to be based on shuttle components. However, once on orbit, Option C carries a performance penalty in capability, by virtue of its reliance on older technology and shuttle-unique systems. The system has a shuttle-unique data bus and a shuttle-unique (vintage 1980) processor. The system software is written in a language unique to the shuttle. Immature definition of interfaces with user, international, and Freedom-derived systems may lead to eventual system growth, with a commensurate risk of cost growth.

Option C has fragile radiators and solar arrays, which limits orbiter operations in the proximity of the station. The limited data system includes less pervasive instrumentation to monitor and characterize the engineering functions. In terms of attitude, Option C must make a compromise. Choices include an attitude such that the solar arrays point at the Sun, which provides more electrical power but poorer microgravity and viewing, or an attitude oriented towards Earth, which provides less power.

Option C need not incur a tradeoff between attitude (microgravity environment) and power. With a simple "drag make-up" system, the microgravity environment near the center of mass can be controlled to better than 0.1 microgravity on all axes. If a biased constraint value (say 0.5 microgravity) is desired, it could also be obtained. Such a system would use 12 thrusters with about 0.1 pounds capability. It is being designed by engineers at the Johnson Space Center, but is not yet in the baseline.

Option C is a capable space station, but somewhat less capable than Options A and B. If selected, Option C should be carried to its full power capability at permanent human capability.

Growth Capability of Options

The potential for growth in scientific and engineering experiments to be conducted on the station is significant. It is quite clear that the results of experiments now scheduled cannot be anticipated, and, therefore, the follow-up tests that will naturally flow from success or surprise cannot be planned. More fundamentally, biological and physical sciences are moving so rapidly that the ability to modify, enhance, and replace experiments becomes an essential feature that the station provides.

The redesign options respond differently to this need for growth capability. Option C provides considerable interior growth and flexibility with its large pressurized volume of 1117 cubic meters. However, the opportunities for external experiment growth are quite limited. By contrast, the two options most closely related to the baseline design, Options A and B, have the reverse characteristic. They have less growth capability in their smaller pressurized volume, 760 and 878 cubic meters respectively, but have substantial opportunities for exposed experiments on their extended truss structure. Exploiting this capability requires robotics, which are quite strong in Option B, or additional EVA. However, because EVA

is limited, and most currently planned experiments do not seek exposure to the external environment, initial growth capability favors Option C. A further complicating factor, however, is that Option C's additional capacity is limited in its utility by a shortage of available power, which cannot be provided as easily as for the other two options. Options A and B offer the potential for evolutionary growth with the addition of more laboratory modules and power capability after permanent human presence.

Internal growth capability favors Option C, and exterior growth needs favor Options A and B. Thus, growth capability is not a strong discriminator.

Science, Technology, and Engineering Research

When assessing the capabilities of the several redesign options, it is important first to evaluate the considerations and assumptions that have produced the "requirements" by which each of the options are being evaluated. The "requirements" must follow from those research investigations that have survived the prioritizations and competitive evaluations as discussed in the Mission and Requirements section. This is even more critical for a redesigned station, where important savings in costs are being sought, and where unnecessary requirements could drive costs in an unacceptable direction. In a redesigned program, the redesign of key pieces of research hardware should also be considered in order to achieve possible savings in the requirements for energy demand, volume, etc. It is important that in a redesign, the addition of requirements above those in the present Space Station Freedom Program should be carefully monitored.

The Station Redesign Team effort considered the total planned and ongoing NASA research programs in microgravity and life sciences, as well as in engineering research and in the ongoing commercial programs. Hence, there is, in the redesign program plan and its costing, substantial use of Spacelab capabilities, shuttle "utilization" flights to the station (some of which may be shared with outfitting or logistics flights), and research cooperation with Russia on the Mir space station. The following payloads are among the key ones included for the highest priority research objectives:

(a) Space Station Furnace Facility—launch 1998

(b) Fluid Physics Dynamics Facility—launch 1999

(c) Gravitational Biology Facility—Spacelab research, to transition to station

(d) Human Research Facility—Spacelab research, to transition to station

(e) 2.5 m centrifuge and habitat holding facility—launch 2004 (rotor to be launched as part of station design in Option C)

(f) Spacecraft Materials and Coatings Facility—launch 1999

(g) Generic commercial/technology payloads

The stated redesign plans for the development of the facilities, especially the microgravity facilities, make maximum use of NASA laboratory personnel and equipment.

Not included in this list are laboratory support equipment for the station and equipment for research on Mir in support of the overall research program. Also not

	Option A		Option B		Option C		SSF
	IHTC	PHC	IHTC	PHC	IPHP	PHC	PHC
Crew Size[1]	4	4	4	4	4	4	4
Max. On-Orbit Crew d/yr	80	365	80	365	365	365	365
Research Crew Hr/yr	1444	6724	1370	6566	6884	6866	6566
Power to Users, kW orbit average	18	31	41	40	14/37[2]	26/55[2]	34
Environment[3] O_2 %	21	21	21	21	21	21	21
CO_2 %	0.5[4]	0.6[4]	0.5[4]	0.5[4]	0.6[4]	0.6[4]	0.74
psia[5]	14.7	14.7	14.7	14.7	14.7	14.7	14.7
Voltage[6], VDC	120	120	120	120	28/120	28/120	120
Racks to Users[7]	39	39	49	46	72	72	46
User Racks <1 microgravity	0/29[8]	8	16/21[8]	29	40	40	29
User Racks < 2 microgravity	14/39[8]	36	31/38[8]	45	72	72	45
External Attach Sites[9]	17	21	15	15	14	14	14

1 An 8-person crew at permanent human presence has been recommended in a National Research Council report
2 Local Vertical/Solar Inertial
3 No closed life support system in any option
4 A 0.3% CO_2 composition has been recommended by the NASA Aerospace Medicine Advisory Committee, and is achievable for all options on a periodic basis
5 The pressure may decrease to 10.2 psia during EVA activities
6 Voltage conversions on a rack-by-rack basis
7 Acceleration mapping system included as station-supplied in all options
8 Orbiter attached/unattached
9 Utility of attached sites depends upon particular option

Figure 11. Comparison of Options: Research Resources

included is the "development of life support and medical care capabilities [which were] incorporated [and budgeted] as subsystems in each option." In this latter activity area, there is likely to be considerable overlap between station life support and medical care capabilities and important research related to the capabilities of humans in long-duration space flight. The management of these two aspects of the space station program needs to take into account the overlap and synergism of these two areas of human space flight so that the maximum in scientific understanding can be achieved.

In terms of the first priority research objectives with a space station, orbital inclinations between 28.8 and 51.6 degrees are satisfactory.

Option A

When the shuttle is attached to this option prior to and at international human-tended capability, the center of the 1 micro-g ellipse will be located in the shuttle bay. The microgravity resources are listed in Figure 11. The acceleration features during human tending, as well as during permanent human capability, could pose some limitations on the nature and scope of the microgravity research projects that might be carried out. Another potential limitation (depending upon the research requirements) on the acceleration environment is produced by the fact that the station in this option must periodically roll in 90 degree increments in order to acquire the best orientation for power generation. The time intervals between roll maneuvers will vary between 7 and 59 days. During the intervals when a shuttle is not attached in the international human-tended phase, some microgravity research might be carried out in a robotic, untended mode.

Option B

Since Option B is a scaled-down version of Space Station Freedom, a number of the research capabilities are more extensive than those available in Option A, as would be expected. For example, the power available at the international human-tended phase is the same as the power available at the permanent phase, about 40 kW.

In the international human-tended phase, the center of gravity of the system is in the laboratory of the attached orbiter. At permanent human capability, there are more low-g racks than in Option A.

Option C

This option has the greatest total pressurized volume of all options. Although the acceleration environment for most microgravity experiments appears to be satisfactory in the arrow flight mode, the solar inertial attitude flight will have a significant detrimental effect on fluid experiments, including melted materials that are being crystallized, and on some combustion experiments. The solar inertial mode will induce a rotating acceleration vector in such fluid materials. There may be a method of compensation for this problem. This has not yet been examined in detail for a station.

Passive attached engineering payloads such as materials exposures and orbital debris measurements cannot be flown in a solar inertial attitude. Such research can be carried out in the arrow flight mode provided an active attitude-sensing system is used with the payload.

In summary, there are not sufficient over-riding differences in the three sets of capabilities for life sciences, human adaptation, and microgravity research to be a determining factor in the choice of a specific redesign option.

Impact of Number of Crew

Reduction of crew to four from eight implies that two near full-time researchers will be available to conduct experiments for 90-day increments beginning with human-tended capability. Pilot-crew may also assist in some phases of research. All previous examinations of crew composition for space station missions recommended a minimum of four researchers. The present proposals will place significant limits on station research productivity in several high-priority areas. During the human-tended and permanent human presence phases, the research requirements will be constrained by the number of crew and their disciplinary qualifications. A comprehensive crew health care system, including carefully considered

duty cycles and off-duty activities, must be developed to assure optimal crew performance during long-duration space station activities.

The pilot qualifications for flight are well-established by NASA. The research crew members in a small crew must consist of mission specialists who have appropriate technical backgrounds and the opportunities to maintain scientific and technical proficiency. Specialized backgrounds may be appropriate for crew members working on the highest priority experiments, whereas generalists may be more appropriate for complex interweaving of scheduled diverse disciplinary experiments. Crew assignments should be balanced carefully with the research objectives. NASA should reexamine both its crew selection criteria and its ongoing programs for maintaining astronauts' scientific and engineering technical proficiencies.

Comparison of Performance

For systems as complex and diverse as the space station, no adequate measures of merit are suitable to unambiguously define an optimum system. Comparison of the options requires both broad qualitative and detailed quantitative perspectives. The qualitative comparison was presented in the two previous subsections.

The options are quantitatively differentiated by how well they support the five principal objectives of the space station. This is summarized in Figure 12. The principal program objectives are: research, comprising microgravity and life science; engineering; international cooperation; commercial opportunities; and human exploration. The ranking of the options was based on the quantitative parameters of Figure 13, plus other factors that impact utilization, such as data management system capability, attitude, utility for proximity operations, etc.

Microgravity science is rated for power and microgravity level. This includes not only low frequency but also dynamic components. The life science rating reflects the ability to do rack level experiments on biological processes, and assumes a small centrifuge. Examining Figure 12, it is evident that by the time permanent human capability is reached in the three options, the ability to do scientific research is not a strong discriminator.

The criteria used to evaluate engineering research capability include: the ability to extend, enhance, and replace space station systems in orbit; the provision for engineering attached payloads; and the instrumentation of the space station system. The modular nature of the systems in Options A and B, together with the more capable data system and number of external payload attachments, give them an advantage over Option C.

The international accommodation is rated against adherence to the Memoranda of Understanding and Intergovernmental Agreements. The ranking favors Options A and B. For a more detailed discussion, see the section titled International Partners' Assessment.

Commercial utilization requires a policy to encourage industry participation plus a worthwhile capability to be used. The policy must state the cost of use, access, priority for on-board resources, and protection of proprietary data. Commercial use policy should encourage nontraditional uses. The Administration should state a clear policy for commercial use of the space station. The capability needed by commercial users could not be distinguished from that needed by the microgravity, life sciences, and engineer-

CATEGORY	OPTION A-			OPTION B			OPTION C		
	HTC	IHTC	PHP	HTC	IHTC	PHP	U.S. PHC	IPHP	PHC
1. *Science; Long Duration Space Research:* 1A. Microgravity--Microgravity Level and Power (capacity to support ovens, etc.)	60	80	100	60	100	100	80	60	100
1B. *Life Sciences* (distinguished from Human Performance) Centrifuge	40	60	100	40	60	100	100	100	100
2. *Engineering; Development of Technology and Skills:* A. Extend, enhance, replace SS functions on orbit B. Attach, adjust and observe external payload C. Instrumentation of SS functions for performance, identification and effects of the environment D. Racks, power and standard test equipment	40	60	80	40	60	100	40	60	60
3. *International Cooperation in Science and Technology:* Meet IGA (external can, power, data, communications, microgravity, and habitability)	0	40	80	0	40	80	0	40	60
4. *Commercial; Opportunities for Industrial Users:* Easy access to space including volume, racks, power, external attach points, crew and simplified processes.	40	60	100	40	60	100	80	80	80
5. *Human Exploration:* New clinical data on extended human flight (more than one year)	0	0	100	0	0	100	100	100	100
Estimated Date of Option Availability	**Jul 1998**	**Jan 2000**	**Oct 2000**	**Dec 1998**	**Mar 2001**	**Dec 2000**	**Nov 1999**	**Oct 2000**	**Jun 2001**

Abbreviations:

HTC = Human-Tended Capability
IHTC = International Human-Tended Capability
PHC = Permanent Human Capability
U.S. PHC = U.S. Permanent Human Capability
IPHP = International Permanent Human Presence

Figure 12. Evaluation of the Options for the Five Principal Uses of the Space Station (in Percentage of Desired Capability)

ing users. The ranking that appears in Figure 12 reflects an average of those three categories.

Long duration exposure of humans to space conditions will gather the data necessary before a decision to explore the solar system with humans can be made. The ranking of this was quite simple. If human presence in excess of a year is possible, it received a full score. If not, it received none. The preparation for human exploration is a clear discriminator between human-tended and permanent human phases. It does not distinguish between the options.

As an assessment of whether the space station represents a true advance in capability, the three options under consideration were compared with the baseline Space Station Freedom, Skylab, and the Russian Mir Space Station (Figure 14). The ratings are assigned on the same basis as those of Figure 12.

All of the options considered, if carried to permanent human presence, would provide substantially greater capability than previous stations.

Schedule

None of the redesign options meets the White House goal to complete development by the end of October 1998. However Option A does reach its human-tended configuration by this point in time.

A comparison of nominal schedules for the three options is shown in Figures 15 and 16. The first depicts the launch sequences for a 28.8° orbit inclination angle, and the second depicts a launch to 51.6°. Somewhat complicating direct comparisons of the options are the differences in station buildup strategies. Options A and B have a human-tended phase, during which time the internationals are brought on-board, followed by permanent human capability, which includes the internationals. Option C moves directly to permanent U.S. human capability, and then brings on the internationals.

Comparisons can be made at four schedule points. The first comparison occurs when the stations attain human-tended on-orbit research capability. This is shown by the left line in Figures 15 and 16, and shows that Options A and B reach this point before C is permanently inhabitable at both inclinations. Thus Options A and B provide an opportunity for early human-tended science, and possible intermediate stopping points. Option C has no human-tended phase.

The second comparison occurs when full capability is achieved, with permanent human capability, internationals, and full power. This is shown by the line on the right side of Figures 15 and 16. This comparison is not a discriminator between Options A and C at 28.8°. At 51.6°, Option A is completed about a year before C.

The third comparison is permanent human capability, achieved earliest by Option C, but without the internationals. The last comparison is the date the international modules are complete. This occurs earliest in Option A, next in Option C, and last in Option B.

The number of shuttle flights needed to reach each comparison point is indicated in Figures 15 and 16 for the two inclinations being considered. Looking beyond assembly completion, the research station function will be supported by five to six logistics flight per year, for the 10 to 15 year lifetime of the station.

	Option A			Option B			Option C		
	HTC	IHTC	PHC	HTC	IHTC	PHC	U.S. PHC	IPHC	PHC
Max on Orbit Crew Days in Year	80	80	365	80	80	365	365	365	365
Research Crew Hours/Year	1505	1444	6724	1449	1370	6566	6974	6884	6866
30-Day Max Port Power (kW)	19	39	46	19	59	59	54/29*	49/29*	57/37*
Pressurized Volume	110	491	760	219	680	878	736	1117	1117
User Rack	9	39	39	16	49	46	40	72	72
User Racks < 2 μg**	9/0	39/14	36	10/16	38/31	45/28	40	72	72
External Payload Site	10	17	21	2	15	15	4	14	14

Abbreviations:

HTC	=	Human-Tended Capability
IHTC	=	International Human-Tended Capability
PHC	=	Permanent Human Capability
U.S. PHC	=	U.S. Permanent Human Presence Capability
IHPC	=	International Human Presence Capability

* Solar Inertial Local Vertical/ Local Horizontal

** Without/With the Orbiter Attached

Figure 13. Quantitative Comparison of Options' Research Resources

Category	Skylab	Mir	Spacelab	Freedom	Option A (PHC)	Option B (PHC)	Option C (PHC)
Microgravity	20	40	40	100	100	100	100
Life Science	60	60	80	100	100	100	100
Engineering Research	40	60	60	100	80	100	60
International	0	40	60	80	80	100	60
Commercial	40	60	60	100	100	100	80
Human Exploration	0	100	0	100	100	100	100

Figure 14. Comparison of Various Stations with Redesign Options (In percentage of desired capability)

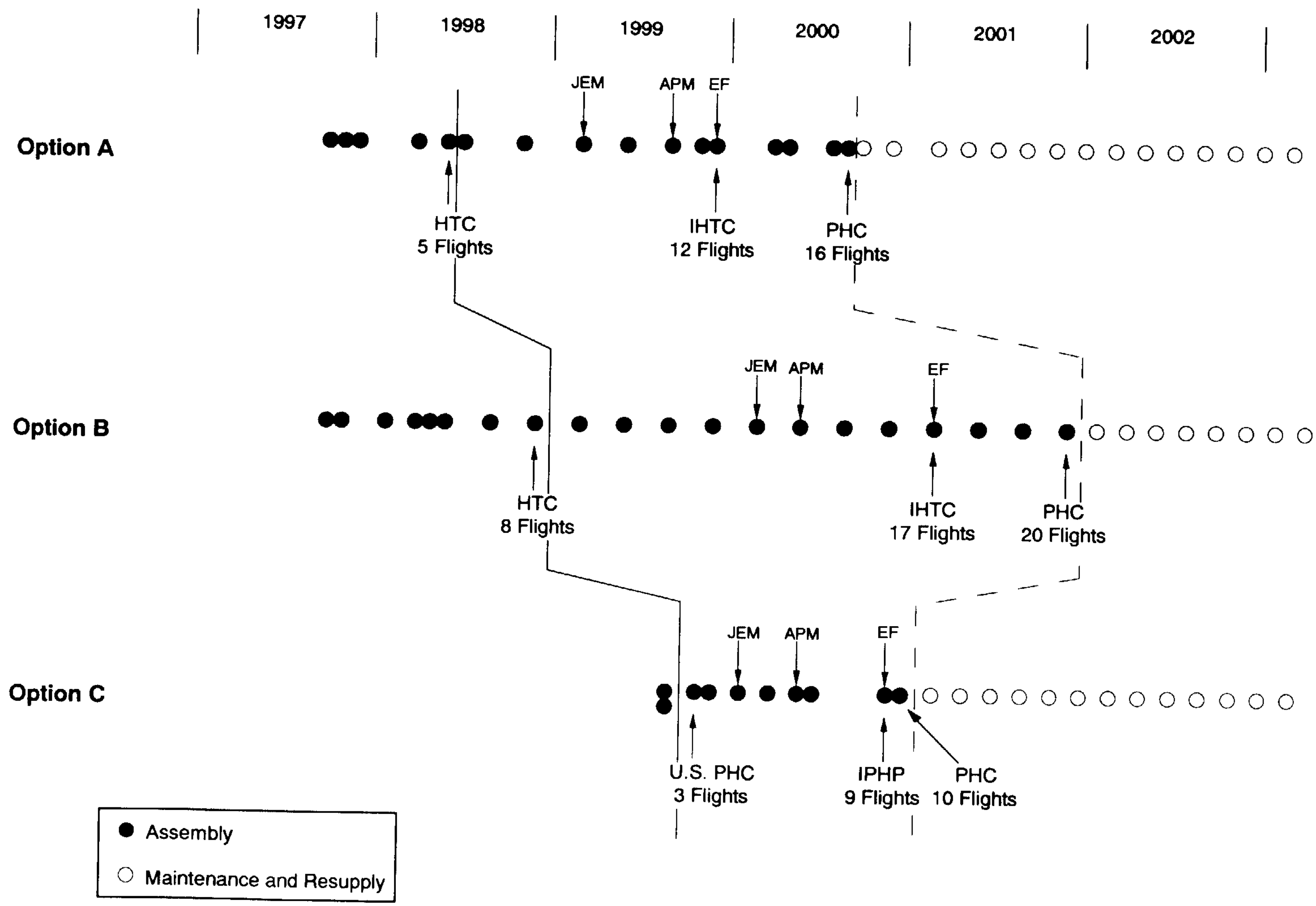


Figure 15. Space Station Assembly Schedule at 28.8°

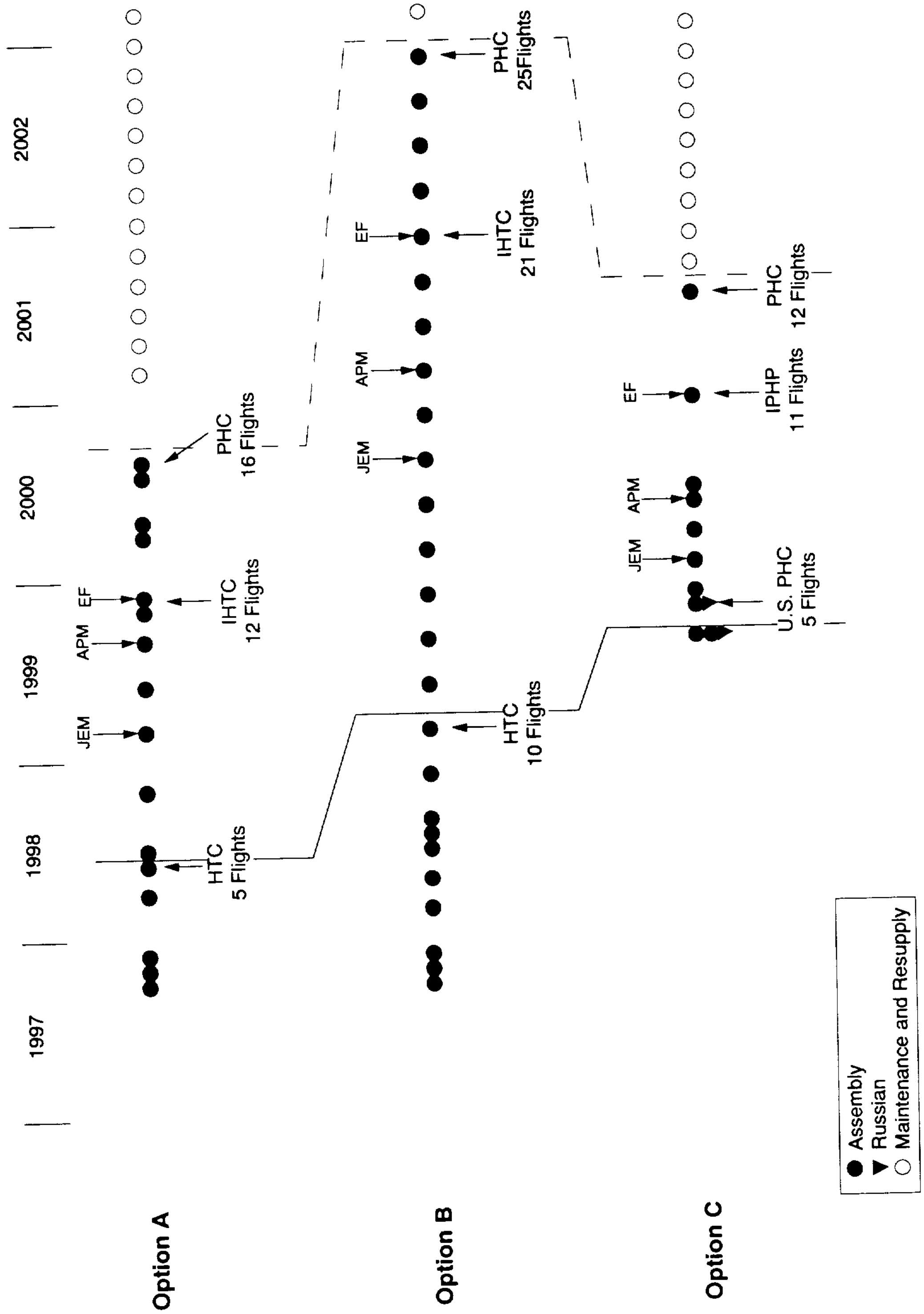


Figure 16. Space Station Assembly Schedule at 51.6°

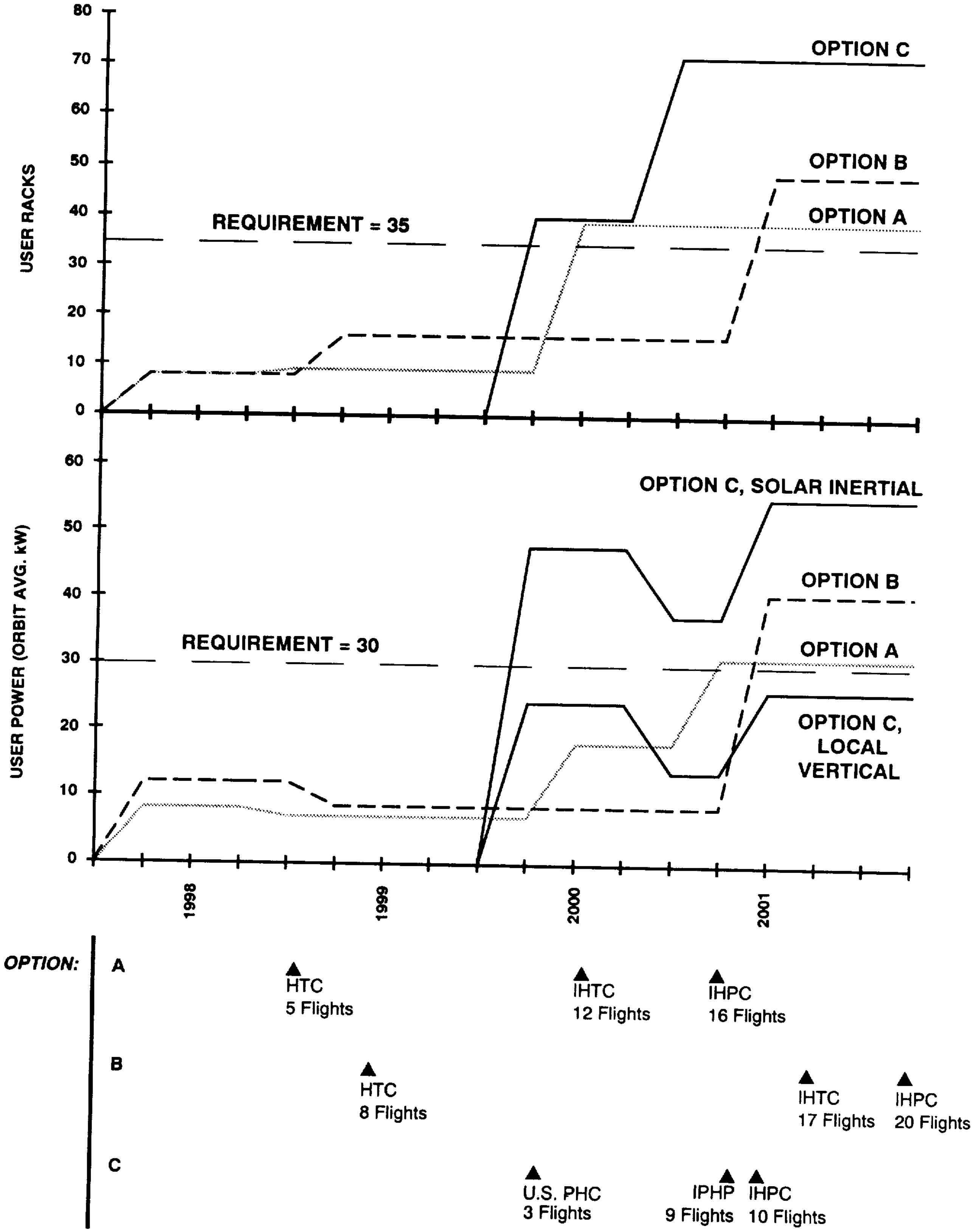


Figure 17. Fundamental Capacity and Launch Phases Versus Time at 28.8° Inclination

Using the measures of user power and equipment racks as approximate indications of station capability, Figure 17 shows these quantities versus time. The following observations can be made from this figure:

- Options A and B provide the earliest user capability. They do so in late 1998. Full capability is achieved in early to late 2000 respectively.
- Option C provides significant initial capability in late 1999. The final capability is obtained in late 2001.
- Options A and C meet the rack and power requirements at approximately the same time, in late 1999.

Option A and B have 18 and 9 month head starts respectively on C. On the other hand, only a fraction of this time will be available for scientific human-tended activity because of continuing on-orbit assembly and checkout operations. When Option C is launched in the fourth quarter of 1999, it surpasses the requirements and the capabilities of Options A and B. If the proposed micro-g environment controller is used on Option C, the vehicle can remain oriented to the solar inertial mode most of the time. This would ensure adequate power with the initial launch. In turn this would accelerate the final capability by several months to the fourth quarter of 2000, since the third power module would not be required.

In summary, Option A achieves human-tended research and international presence earliest. Option C achieves permanent human presence earliest, and both reach ultimate capability at about the same time, well before Option B. On average, schedule is not a discriminator between Options A and C.

Cost

Overall Assessment

The Subcommittee on Cost Assessment was provided with cost data to the subsystem level for all options, summary data by program cost element, and supporting rationale. Additionally, the results of the 3-month NASA independent cost analysis of Space Station Freedom were reviewed. Members of the Committee also visited the facilities of the three Space Station Freedom prime contractors, Boeing, McDonnell-Douglas, and Rocketdyne, to participate in briefings, candid dialogue, and to observe work in process and end products. [A glossary defining customary cost terminology used in this section is provided as Appendix E.]

The Station Redesign Team cost assessment group conducted the costing process for the redesign effort. Each option was led by an experienced lead cost estimator with technical familiarity with the processes, products, and unique characteristics related to a specific option and its relationship to the appropriate NASA institutional capabilities and the Space Station Freedom Program.

Funding changes, redirection, and the absence of long-term commitment to Space Station Freedom have clearly resulted in discontinuity, causing increased costs and schedule slips. In an assessment of the definitized contract value history of one of the major Space Station Freedom prime contractors, new requirements and schedule slips resulting from "stop and go" funding were responsible for 80 percent of the contract cost growth over 5 years.

National commitment and appropriation stability are critical components for a successful space station program.

A major issue facing the Administration and NASA is that funding guidelines are not consistent with requirements to develop the three redesign options. The 5-year level funding guidelines fail to recognize the inherent staffing profiles associated with development programs.

None of the three station redesign options meet, in its fully implemented phase, the cost targets of $5 billion, $7 billion, and $9 billion for their Fiscal Year 1994 through Fiscal Year 1998 cumulative costs, including program and all other cost impacts. Nor does any option meet the annual funding target while simultaneously achieving the schedule milestones desired.

Unrealistic funding will repeat the Space Station Freedom experience, where expectations were oversold, which inexorably and successively led to concerns about its progress, causing periodic program reviews, funding/baseline changes, and concomitant inefficiencies and finally to the current redesign effort. Therefore, no matter which option is selected, a national commitment must be made—providing funding stability.

NASA must relentlessly pursue cost-effective goals, such as a significant reduction in management, elimination of the separate Level II operation, the merging of facility functions, and other stated objectives. Doing so will challenge NASA, but is critical to the program's success. Not doing so will certainly lead to continued cost and schedule overruns.

Although none of the options meets the targeted funding goals (Figure 18), a comprehensive analysis of the costs required to develop any meaningful capability to conduct long-term, on-orbit research indicates that this is a complex, technically challenging, and costly endeavor.

The redesign effort has identified viable options, with credible cost projections, which would permit the development of a very capable station while saving from 6 to 10 billion dollars over the anticipated cost of Space Station Freedom.

Our analysis took into account the results of NASA's Independent Cost Assessment Team's review of the Space Station Freedom Program, who found the baseline program's cost and schedule risk to be substantially understated. The independent team believed that the Freedom pro-

Station Design	FY 94–98 *	Balance to Completion	Date of Permanent Human Capability	Annual Operations
Freedom (Baseline)	14.4	5.6	Sept 2000	2.4
Option A	12.8	3.7	Oct 2000	1.4
Option B	13.3	6.0	Dec 2001	1.5
Option C	11.9	3.3	Jan 2001	1.0

* Administration FY 94–98 Cost Targets are $5 billion, $7 billion, and $9 billion

Figure 18. Cost Comparison of Permanent Human Capability (Real Year Dollars in Billions)

gram required an additional $2.1 billion in funding through Fiscal Year 2000, exclusive of the resources needed to develop an interim assured crew return vehicle. The program's schedule indicated an identifiable 6-month slip to the flight dates, with the risk of additional slips. The assessment suggested that the potential additional slip represented further funding risks, beyond the $2.1 billion shortfall already identified.

A review of the team's findings led to the conclusion that the likelihood of a schedule slip beyond the determined 6 months was high. The additional cost of that schedule slippage is difficult to estimate, due to the probability that an early recognition of the slip potential would lead to taking steps to mitigate the cost growth.

Costs developed for the redesigned station include not only development and operation costs, but also the other directly coupled costs such as crew emergency return provisions, payloads, science institutional support, shuttle modifications and support, unique facility construction, and certain early flight research missions. Redirection of the program involves contractual changes for the Government's convenience that require partial or whole terminations of contractor activities and resultant outlays for a variety of costs, including employee severance pay, facility lease terminations, and liquidation of outstanding purchase orders for parts and materials.

A key element of the cost estimate for each option is the recognition that there is a substantial, realizable savings potential from management, organizational, and contract changes.

The following are cost factors common to all options:

- Requirement for compatibility with the launch and in-orbit capabilities of the space shuttle.
- Requirements of researchers for extremely low microgravity, long-duration stays, rapid and easy access, high power levels, and crew time.
- Provision of capabilities and services to the international partners.

Summary-level costs for the Space Station Freedom baseline budget, the independent cost assessment estimate to complete its development, and the estimates for the three options are shown for the various development phases in Figure 19. Figure 20 contains funding requirements by year for Fiscal Years 1994 through 1998 and the balance to completion. These are further discussed in the subsequent option sections. It is noteworthy that only at the power station configuration do the costs fall within the $5 billion, $7 billion, and $9 billion threshold. Human-tended capability exceeds the threshold goal by 16 to 30 percent. The distributed costs for major systems and functional elements of Space Station Freedom and the three options are displayed in Figure 21.

NASA provided data that indicated cost increases for crew return vehicles and shuttle integration bring total costs for the 51.6^{o} inclination to:

Option A — $17.0 billion

Option B — $19.7 billion

Option C — $15.5 billion

Orbital Inclination 28.8°	Space Station Freedom Baseline		SSF NASA Cost Assessment		Option A		Option B		Option C	
Phases	$	Date	$	Date	$	Date	$	Date	$	Date
Power Station					5.7	Dec 1997	6.3	Nov 1997		
Human-Tended Capability					10.5	Jul 1998	11.8	Dec 1998		
International Human-Tended Capability					13.4	Jan 2000	16.4	Mar 2001		
U.S. Permanent Human Capability									13.7	Nov 1999
Permanent Human Capability	20.0*	Sep 2000	25.1	Mar 2001	16.5	Oct 2000	19.3	Dec 2001	15.1	Jan 2001

* Does not include assured crew return vehicle

(shaded) = not applicable

Figure 19. Space Station Cumulative Cost and Schedule Comparison (Real-Year Dollars in Billions)

Inclination 28.8°	1994	1995	1996	1997	1998	Balance to Completion
Freedom*	2.5	2.8	3.1	3.0	3.0	5.6
Option A	2.3	2.7	2.8	2.6	2.4	3.8
Option B	2.3	2.6	2.9	2.8	2.7	6.0
Option C	1.8	1.9	2.8	3.0	2.4	3.3

* *Baseline*

Figure 20. Space Station Annual Funding Requirements Permanent Human Capability (Real-Year Dollars in Billions)

Inclination: 28.8 Function	Space Station Freedom Baseline Through Sept 2000	SSF NASA Cost Assessment Through Mar 2001	Option A Through Oct 2000	Option B Through Dec 2001	Option C Through Jan 2001
Total Cost	22.1*	25.1	16.5	19.3	15.2
Development	7.4		7.4	9.0	7.6
Operations	7.3		3.7	4.7	2.2
Allocated Costs	.7		.8	.9	.8
Transition	—		—	—	.2
Crew Return Vehicle	—		.4	.5	.4
Facilities	.2		.05	.05	0
Shuttle Integration	.5		.8	.7	.6
Payloads	2.2		2.3	2.5	2.3
Research Support	1.7		1.1	1.0	1.1
**Independent Estimate Increase to Budget Baseline*	2.1				

Figure 21. Space Station Cost Comparison Permanent Human Capability (Real-Year Dollars in Billions)

Option Specific Assessment

Option A

The total cost of Option A-1 and Option A-2 falls within the target costs only at the power station development phase and exceeds the goal at subsequent development phases. Although only the power station for Option A meets the funding profile of $1.9 billion/year, the Station Redesign Team has done a credible job estimating these options, and the funding profiles are realistic. The Allowance for Program Adjustment reserves are realistic for an effort of this complexity. The Redesign Team's risk assessment is based on detailed analysis at a subsystem element level. The Committee's review of this data provides confidence in the credibility of the cost estimate.

The cost estimates are calculated on the premise that the necessary contract termination and/or descopes will be effective July 1, 1993, although this is an aggressive assumption. A timely decision and

the ability of the transition team to react quickly can offer substantial savings both in terms of cost avoidance and the initiation of the redirected efforts.

It is desirable to go to a single contractor for integration responsibilities, and a strong Program Manager should have the flexibility to either direct the other contractors to a subcontractor relationship or a formal associate contractor relationship. With this implementation, the separate Level II operation now employed by Space Station Freedom is eliminated, though some of these functions and associated costs will be required for the new designated Prime/Integrator.

An additional element of cost is the cadre of civil service personnel currently supporting the Space Station Freedom Program. It is considered appropriate to transition some of the current contractor tasks, i.e., engineering analysis, safety/reliability, and mission control to civil servants. The Program Manager should be given flexibility to make the trade-offs between civil service and contractor personnel during the transition phase. The Committee also concurs with the Redesign Team's model staffing matrix, which shows a 24 percent total reduction in personnel: 18 percent contractor and 32 percent civil service, including the elimination of the separate Level II operation support. Further reductions may be achievable, but this option already contains management reductions implemented in early 1993.

The validity of the cost estimates is dependent upon the appointment of an effective and empowered transition team with a strong program manager as soon as a decision is made on the option.

Option B

None of the development phases of Option B meets the Administration's cost goals, but the estimate for this design appears accurate. The funding profile is realistic even though it does not meet the $1.9 billion/year goal. The reserve and allowance for program adjustments are realistic for an effort of this complexity even though they have completed several Critical Design Reviews.

The cost estimates are calculated on the assumption that the necessary contract termination and/or descopes will be effective July 1, 1993. This is possible since this does not depart drastically from the current baseline. A timely decision and the ability of the transition team to react quickly can effect substantial savings both in cost avoidance and the initiation of baseline changes.

The costs assume that Option B will also be integrated under a single contractor. The Program Manager should have the flexibility to either direct the other contractors to subcontractor relationships or to formal associate contractor relationships. The separate Level II operation is eliminated for this implementation; however, as in Option A, some of these costs will still be incurred by the Prime/Integrator.

The cadre of civil servants is a program cost not included in these estimates. However, the utilization of civil service personnel for performing some of the support contractor tasks such as safety/reliability issues, engineering analysis, and console operation in the mission control center is considered appropriate. As in Option A, the Station Program Manager should be given flexibility to make tradeoffs between civil service and contractor personnel during the transition phase.

The cost estimate for Option B assumes the Redesign Team's model staffing matrix showing a 25 percent total reduction in personnel: 18 percent in contractor personnel and 32 percent in civil service, including the elimination of the separate Level II operation support. Further reductions may be achievable; however, it should be noted that this Option also contains management reductions implemented in early Fiscal Year 1993.

The validity of all these cost estimates is dependent upon the appointment of a strong transition team to go to work as soon as a decision is made on the option.

Option C

The cost estimating approach for this option reflects the hybrid character of the design and development approach for new structures and mechanisms, and unit cost data for shuttle, Space Station Freedom, and Spacelab hardware components. An assumption made in costing Option C is that the station is embedded within the overall shuttle management environment, thus saving a layer of management.

Option C does not meet the development cost goals at any phase of development, nor does it meet the annual phasing targets. It is questionable whether the reserves and Allowance for Program Adjustment are adequate for the schedule proposed. The maturity level of this design is significantly lower than Options A and B even though portions of it are well understood. The cost of modifying the shuttle facility interface with almost half the systems on Option C that are not orbiter derived may be greater than estimated. The cost of the recertification and other processes requiring the use of Columbia's aft structure and engine are still unclear.

Once again, the cost estimates are calculated on the assumption that the necessary contract terminations will be effective July 1, 1993. It is unlikely that both the White House and the Congressional appropriations committees will take the action necessary for this option in a timely manner, as it requires the termination or subordination of the existing contractors and the establishment of a new sole source contractual arrangement.

Option C is a new development even though it may have considerable inheritance from the shuttle and Freedom programs. In the absence of Congressionally approved reprogramming, there may be no authority to use available funds in Fiscal Year 1993 to initiate the desirable preparatory actions if Freedom is terminated. Authority to proceed in Fiscal Year 1994 requires completed legislative actions and the President's signature on new appropriation. The ability of these offices to react quickly can effect substantial savings both in terms of cost avoidance and the ability to initiate the redirected efforts.

Completed action by October 1, 1993, is not a high probability. Also, in the event of a Continuing Resolution, "new starts" are not eligible for funding unless there is specific authority in the resolution language. Therefore, the dates for Option C are at high risk in planning and scheduling action.

Risk Assessment

Option A

The risk factors associated with Option A include EVA for assembly and maintenance, the number of shuttle flights required to assemble the station, flight schedule uncertainties, design maturity, ground integration and verification, and on-orbit assembly and checkout. Option A depends completely on the space shuttle for launch of components and requires no new launch vehicle. Overall, Option A must be considered a high risk, as discussed below.

A very significant number of EVA hours (currently 224 hours) would be needed to assemble the Option A station. While somewhat less than the requirement for the baseline station, the EVA workload and associated risk to successful completion and to flight crew safety are substantial. In addition, several thousand station maintenance components would be located outside the pressurized volume and would require EVA for routine maintenance or replacement. Although EVA has been shown to be a versatile use of humans during spaceflight, the workload is high, and experience indicates that no ground-based training facility provides the fidelity needed for some complex and sensitive operations. Total dependence upon the integrity of the spacesuit makes the crew member susceptible to micrometeoroids, space debris impacts, or critical system failures.

This option would require 16 space shuttle flights to complete assembly. Dependence upon a tightly coordinated and successful shuttle launch schedule is an inherent risk, since each flight would carry critical, often one-of-a-kind, hardware. Flight delays could delay assembly, increase cost, or under some circumstances, threaten the entire program. A shuttle accident might result in a major flight interruption and loss of critical components.

For high inclination orbits, the flight schedule requires development of the aluminum-lithium external tank, potentially the advanced solid rocket motor, and on-time availability of station hardware. If required, on-time availability of the advanced solid rocket motor is a major risk item. Launch of the "common module," which is heavier than early components of Option B, would require more boost capability or placement at a lower altitude. The flight schedule risk increases with time due to the number of shuttle flights carrying critical components.

The design maturity of Option A components is relatively high. Many components are derivatives of or identical to those planned for the baseline station, with a number of desirable simplifications. An option to use the well-proven Bus-1 for attitude control and propulsion may be selected. The integration of these components has not been evaluated in a Critical Design Review process. In addition, a number of fundamental questions about orbital debris protection, spare part availability, and likelihood of critical component failure during assembly raise doubts about the viability of the design.

A number of critical uncertainties associated with avionics integration, software verification, and systems management also remain. Prior to launch, it would not be possible to conduct a fully integrated test of all flight hardware. Some components would already be in space by the time others are built and available for testing.

On-orbit assembly and checkout would be highly complex, requiring delivery of components on the space shuttle, and a large

EVA workload. The crew and the flight control team would need to deal with the unexpected, systems failures, troubleshooting, and need for spare parts. To a lesser degree, this is the same as the often cited risk of assembling the baseline station concept. However, the baseline station has a mobile transporter that enhances robotic operations in the assembly process. Lack of this capability will place added stress and complexity on EVA assembly operations and significantly increases risk.

Option A is a high risk option during the critical launch and assembly operations.

Option B

The risk factors associated with Option B include EVA for assembly and maintenance, the number of shuttle flights required to assemble the station, flight schedule uncertainties, design maturity, ground integration and verification, and on-orbit assembly and checkout. Option B depends completely on the space shuttle and does not require development of a new launcher. Option B is considered the highest risk.

Option B would require the highest level of EVA (311 hours) for the on-orbit assembly operations. EVA is an inherent risk to flight crew safety, and such heavy dependence on EVA threatens the success of station assembly. In addition, several thousand components outside the pressurized volume would require EVA for routine maintenance or replacement, and analysis indicates that the planned 187 hours per year of additional EVA for maintenance may be inadequate. Crew members have demonstrated that they can perform significant tasks during EVA. However, ground-based training facilities can not always provide full fidelity to ensure successful operations.

Option B would require the largest number of space shuttle flights to complete assembly (20 flights for permanent human capability). It, therefore, has the highest risk associated with dependence on a timely shuttle launch schedule. Flight delays, of the type often experienced in the shuttle program, would delay assembly and increase cost. A shuttle accident might result in a major flight interruption and loss of critical components, since each flight would carry critical, often one-of-a-kind, hardware.

The risk to the schedule for the first flight to a 51.6° orbit is approximately the same as outlined for Option A, requiring early development of the aluminum-lithium external tank and on-time availability of station hardware. The flight schedule risk to achieve a complete station would be higher than for Option A due to the increased number of shuttle flights carrying critical components.

The design maturity of Option B components is higher than that of the other options. Its components are identical to those planned for the baseline station. This design option maintains what appears to be unnecessary complexity which further increases development risk. The Critical Design Review leaves a number of critical problems. Negative electrical power margins, inadequate orbital debris shielding, lack of EVA margins, incomplete design drawings, module weight growth, unavailability of spares, and critical component failure probabilities during assembly threaten the viability of the baseline design.

This option would have the highest risk associated with systems validation. A number of uncertainties are associated with the data management system, flight software verification, and avionics integration. The systems are highly complex

and cannot be fully tested and integrated on the ground, since some components will already be in space by the time others are built and available for testing.

In summary, Option B would have the most complex on-orbit assembly and checkout, but unlike Option A, is supported by a fully capable robotic system. It would have the largest number of components delivered in space for assembly, subject to failures requiring spare parts and the greatest dependence on a sustained space shuttle flight rate. It would also have the highest EVA requirement for assembly operations. These have been the most often cited risk areas for the baseline station; therefore, this option has the highest risk in this area.

High shuttle launch rate, narrow performance margins, EVA, and assembly complexity make Option B the highest risk option.

Option C

The risk factors associated with Option C include development of a shuttle-derived launch vehicle, the number of subsequent shuttle flights required to outfit the station, flight schedule uncertainties, and design maturity. It requires the least number of assembly flights, the lowest level of EVA, can be fully constructed and checked out on the ground, and has simplified on-orbit checkout. Option C is the lowest risk option.

The shuttle-derived launch vehicle required by Option C is a new development based on several years of studies related to the "Shuttle-C" concept. It uses basic shuttle components and has been subjected to analysis and wind tunnel tests. To the degree that it is a "new" launcher, it still carries significant cost, schedule, and performance risks.

Option C would require a number of space shuttle flights to transport experiment racks, expendables, the international modules, and to support delivery of the assured crew return vehicle. However, the station is permanently manned and operational after three to five space shuttle flights. It has the lowest risk associated with dependence on a timely shuttle launch schedule.

The schedule to achieve first flight has a higher risk than the other options because the launcher and the station hardware designs are relatively new, though based on well-known flight hardware. However, the flight schedule risk to achieve a complete station would be lower than for the other options due to simplicity, minimum components, and lowest need for shuttle flights.

The design maturity of Option C components is low, but the station is very similar to Skylab, using baseline power arrays, space shuttle avionics, and a number of other baseline station systems. The launcher is based on space shuttle components. Overall, the current design maturity risk is greater than that of the other options, but the "schedule to go" risk should be the lowest after a solid Critical Design Review.

Option C would have the lowest risk associated with systems validation since it would use shuttle avionics and software, and it can be completely constructed (except for a number of experiment racks and the international elements) and checked out on the ground.

Option C would have the lowest level of on-orbit assembly and checkout, since it would have the least number of major components delivered in space. (It requires only 12 hours of EVA to attain international capability.) This minimizes one of the most often cited risk areas for the baseline station.

Risk to human life is considerably lower for Option C because it has:

- Less than one-half the manned launches
- Less than one-tenth the EVA assembly hours
- One-half to one-third the EVA maintenance hours, and
- Better micrometeoroid shielding.

In summary, Option C is the lowest risk option to achieve full space station capability.

Overall Comparison of the Options

The Committee's assessment of the redesign options is summarized below:

Option A and B Comparison. While Option A-2 has more capability at lower cost, Option A-1 may be more attractive in terms of risk reduction. The options are similar enough that the Committee will not distinguish between them.

Option A is a desirable simplification of both Space Station Freedom and Option B. Option A is considered by the Committee to be the preferred modular buildup approach, and it is compared below with Option C.

Phase of Development Comparison. Considering the expense of developing a power station ($6 billion) and its limited capability to extend on orbit stay of a modified shuttle beyond 25 days, the power station as a stopping point is not acceptable.

Human-tended capability represents a substantial fraction of the development cost of permanent human capability, but less than 50 percent of its ultimate capability. Thus, the cost/benefit of Options A and B is least attractive at human-tended capability and most attractive at permanent human capability.

In Option C, there is little extra cost in bringing on the international modules and experiments, and the addition of a power module at the permanent human presence phase will cost several hundred million dollars. In view of the small incremental costs, stopping Option C before permanent human presence is not recommended.

Option C and A Comparison. In terms of overall technical and international capability, Option A is somewhat superior to Option C.

Considering development risk, launch risk, on-orbit assembly and EVA, Option C has an advantage in technical risk over Option A.

Option A has an advantage over Option C in achieving an early human-tended capability, but more overall schedule risk through completion.

Overall Conclusion. There are two attractive options that should be seriously considered by the Administration, Options A and C. Option A has an advantage in capability and lends itself to modular buildup. Option C is the lowest risk and potentially lower in cost.

GENERAL MISSION RISK FACTORS

Although not specifically related to the individual options under consideration, various risk factors are important to consider in future developments regardless of the design option chosen. Such risks could delay planned deployment, greatly increase cost, lead to loss of critical station components, result in loss of crew, or substantially degrade mission performance. Risks include unavailability of the selected launch vehicle, accidental loss of a launch pad or other ground facilities, loss of communications with the flight control center, extravehicular activity accidents, orbital debris or micrometeoroid impacts, toxic or biological contamination, in-flight fires, loss of critical systems, radiation hazards, and damage incurred during ground processing.

Accidents and technical problems can "ground" a fleet of launch vehicles. Figure 22 summarizes launch vehicle down times in the past several years. The U.S. shuttle program was dormant from January 1986 until September 1988. During portions of this period, the USAF Titan program and the European Ariane program were also "grounded" due to accidents, resulting in the complete loss of heavy lift capability outside the USSR. Hydrogen leaks also "grounded" the shuttle for 6 months in 1990. The Atlas Centaur has experienced delays of 9 months and 30 months (the total down time includes other than accident-related delays) due to failures. While not related

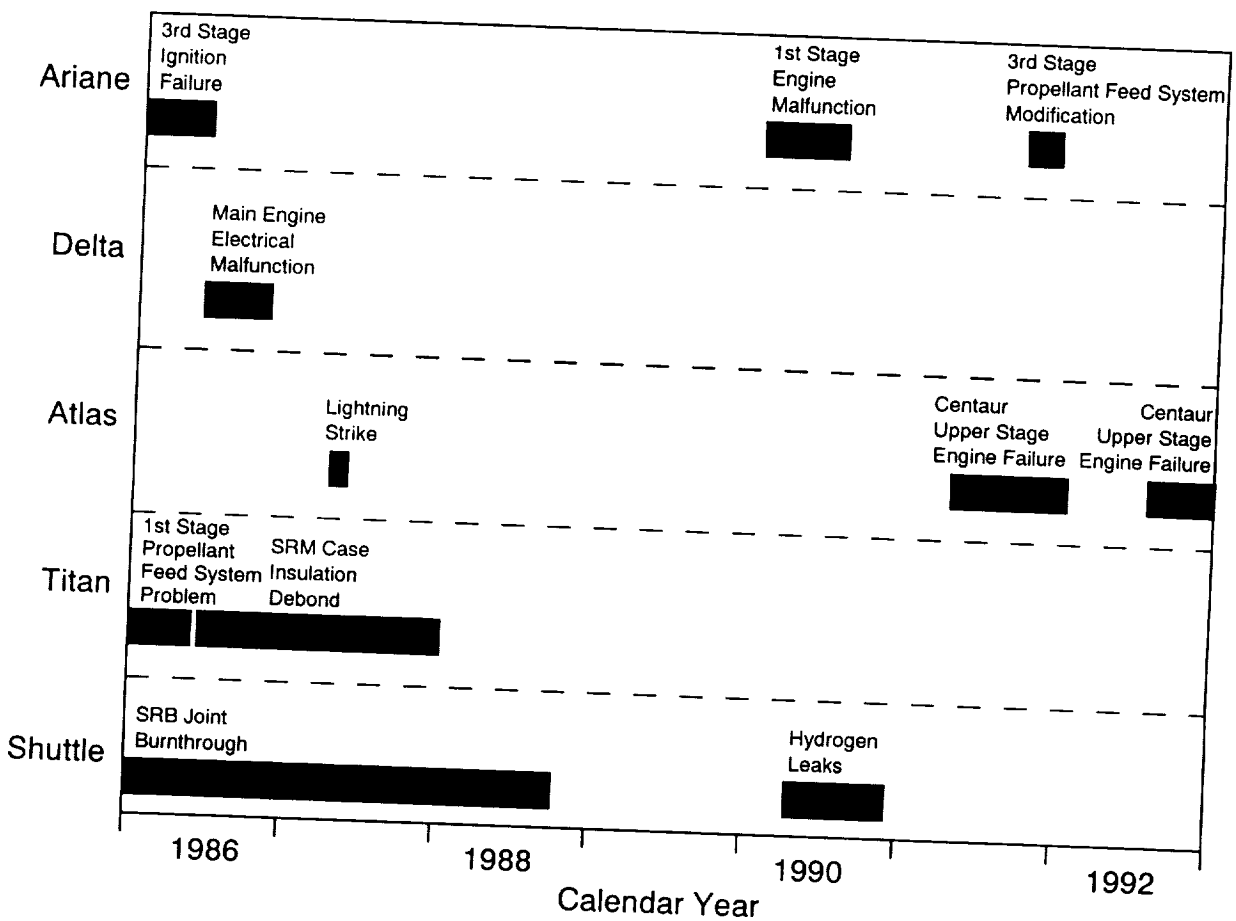


Figure 22. Launch Vehicle Downtimes, 1986-1992

to launcher availability, the Soviet Soyuz program was "grounded" from June 1970 until September 1973 following a fatal reentry accident. On the other hand, a non-fatal Soyuz upper stage failure in April 1975 was followed by a successful launch the following month, and a non-fatal Soyuz explosion on the launch pad in September 1983 was followed by a successful launch in February 1984. The potential for a launch accident and loss of critical station components increases directly with the number of flights required to deploy the station.

Launch pad damage or destruction is also an inherent, but somewhat less likely, risk. In March 1986, a Titan 34C failure at Vandenburg AFB resulted in major launch pad damage and lesser damage to an adjacent launch pad. In 1983, Vladimir Titov and Gennadiy Strekalov survived an explosion of their Soyuz T-10 booster that resulted in major damage to the launch pad. Multiple launch pads for all major launch vehicles provide a degree of redundancy, but at reduced flight rates. In addition, there are a number of single point failures, including launch processing facilities, payload processing facilities, and range command and control centers. Loss of any of these would preclude future launch activities. The potential for loss of launch capability due to any of these reasons, including launcher availability, argues for the dual accessibility afforded by higher inclination orbits achievable with Russian launch vehicles and those of other nations.

Loss of communications can result from the loss of the TDRSS satellite link, loss of ground stations, loss of on-board systems, or configuration obstructions. On the latest shuttle flight, communication was lost for about 90 minutes due to an error by flight controllers. A similar error resulted in the loss of a Soviet Phobos satellite several years ago. The electromagnetic environment can also disrupt communications, and there is some concern about this impact at latitudes associated with higher inclination orbits. Although ground and on-board system redundancy is impressive, a backup to the TDRSS link seems prudent. This is magnified by the inability of TDRSS to simultaneously support data transmissions from the station and a rendezvousing space shuttle orbiter vehicle. The existing UHF backup is very limited in coverage and capability.

The potential for an EVA accident is inherently high due to absolute dependence on the protection and environment provided by the space suit. On the other hand, there have been no accidents in either the U.S. or Russian programs. Most hazards can be prevented with high-fidelity training, but systems failures and micrometeoroids or space debris can be life threatening. The ability of crew members to perform intricate and demanding EVA tasks is well documented in the U.S. and Russian experience. To minimize risk and its potential impact on station deployment, however, dependence upon EVA should be strictly controlled in the design process.

Orbital debris impacts can be extraordinarily hazardous. Objects more than 20 centimeters in size can be tracked by current radars and avoided with station maneuvers. We are limited, however, in our actual capability to track lethal objects and provide timely notice for station maneuvers. Shielding can prevent damage by objects smaller than 1 centimeter. In addition, there remains a high risk due to our inability to track small but lethal objects in the 1 to 10 centimeter size range and our lack of adequate test facilities to simulate their effects. We know that space debris is increasing. Accurate models are still not available to accurately predict the changing environment within

an order of magnitude. Shuttle orbiter windows are replaced due to small cumulative impact pits, and a large single pit was observed on STS-7. Orbiter tiles are also replaced after debris impact damage. Several orbiter flights have taken evasive maneuvers to ensure adequate separation. The debris population is higher, but the velocity alignment is more favorable for shielding at higher inclinations. The Russian Mir station at an inclination of 51.6° has taken several debris impacts that startled the crew, and fist-sized holes have been made in the solar arrays.

Toxic or biological contamination of the station may result from experiments or visiting crew members. There have been several cases of on-orbit leakage of material from experiments. A facility to hold monkeys failed to contain feces and other materials on one of the Spacelab flights. Biological samples have been flown on both Russian and American spacecraft. Air and water samples have been returned for ground testing on numerous space flights. Russians on the Mir station have had a long-lasting battle with fungi that grow in the enclosed environment. Adequate containment, detection, and cleanup capabilities should be considered in the design process.

A fire in the closed environment of a spacecraft is a life-threatening hazard, and much has been done to reduce the likelihood of combustion. Prevention, detection, and suppression are design features. Electrical fires are the most likely type of spacecraft fire, and they can lead to emission of toxic fumes. Several instances of smoking or arcing have been reported on the space shuttle orbiter, but have been readily controlled by turning off malfunctioning equipment. There have been at least two fires on Russian space stations. One of these created a great deal of smoke, but was controlled by identifying the source and turning the equipment off. In the other case, the source was under the cabin floor, and a fire extinguisher was used before turning the power off. The crew used oxygen masks for an extended period in this case due to smoke and extinguisher products in the cabin.

Radiation is a hazard that increases with orbital inclination and altitude. Single event effects influence electronic equipment and require radiation hardened components. Crew radiation dosages are elevated during the portion of orbits over higher latitudes, but at 51.6°, only very short periods are spent in regions of elevated dosage. Environmental monitoring and imposed dose limits will be important factors in design and operations. Russian cosmonauts who were on the Mir station during the intense solar storms of 1989 experienced high radiation fluxes for several minutes on each orbit, but the total dosage was less than preflight limits based on no solar storm activity. However, cosmonauts privately complained that their medical staff was unconcerned about radiation dosage.

Loss of critical systems on the space station is largely controlled by redundant components and on-orbit replacement of failed units. Designers need to be concerned about accessibility of hardware associated with the guidance, navigation, and control system, life support system, data management system, remote manipulator system, and other critical systems and components. Failures are not uncommon, but redundancy has prevented loss of capability in all cases. The ability of the crew to make repairs has been shown to be a vital ingredient in spacecraft systems integrity.

Loss or failure of critical experimental facilities, including the furnaces, airlock, and centrifuge, can preclude numerous scientific operations. This equipment

must be protected from single point failures, funding and schedule uncertainties, and other risks.

During ground processing, there are risks of damaging critical flight hardware during test, assembly, and transportation. The shuttle orbiter and several payloads have been damaged during processing. Risk will probably be elevated if unfamiliar workers or non-standard ground test or handling equipment are used. These risks may be substantially higher if more than one launch site is used to overcome other risk factors.

These mission risks factors are important design considerations. Some represent discriminators between the options. We must remain mindful of all of them, and their consequences, if we proceed with design, deployment, and operation of a space station.

Space flight is inherently risky. The Nation must maintain the proper mechanisms to evaluate, control, minimize, and monitor such risks.

INTERNATIONAL PARTNERS' ASSESSMENT

The following section provides a programmatic assessment, on the part of the International Partner members of the panel, of the initiation, conduct and technical outcome of the space station redesign.

This, the latest in a series of Space Station Freedom redesigns by the United States and, above all, the consequential decisions that will be taken by the US government, will have an impact on the respective programs of the International Partners. The US Partner has explicitly committed itself in the Intergovernmental Agreement (IGA) and Memoranda of Understanding (MOU's) to providing the "Core Space Station" which is essential to the other Partners' contributions, while Canada, Europe and Japan have committed themselves to providing significant elements which together with the US core Station will create an international space station complex with greater capabilities.

The Partners entered into the cooperation in the expectation that this unique partnership would pioneer international cooperation in research and technology development. They considered that it represented a critical step in the human exploration and utilisation of space. The Partners were so convinced of the merits of this arrangement that they significantly restructured their own space programs to make the Space Station one of their cornerstone programs.

We, the International Partners, are all significantly advanced in the development of our respective contributions and collectively have already invested in excess of $3 billion. The current redesign had an immediate impact on our programs, including serious perturbations to plans to release critical industrial contracts. This disruption to our programs will become increasingly problematic until the situation is resolved to the satisfaction of all parties involved.

The Intergovernmental Agreement is the existing legal instrument between the governments of the US, Japan, Canada and nine member states of the European Space Agency, which is considered to have the status of an international treaty. Memoranda of Understanding serve to implement the provisions of the IGA between NASA and its counterpart implementing agencies (CSA, ESA and STA/NASDA). Inherent in the IGA and accompanying MOU's are specific commitments negotiated over a number of years by all of the partners, as to the missions and utilisation of the International Space Station, the overall management of the program, the essential technical contribution to be made by each partner, the sharing of space station resources, the operation and utilisation of the facility once assembled and the sharing of common operations costs.

In 1991, the Italian Space Agency entered into a separate MOU with NASA, ratified at government level in early 1993, to provide two mini pressurised logistics modules and a mini-lab for the International Space Station. This contribution, made in the framework of the US partner contribution, was in addition to the Italian involvement in the ESA contribution.

The US invited its partners to participate in the redesign effort. With the establishment of the Operating Ground Rules agreed to on March 26th, 1993 by the IGA partners and on April 21st by ASI, the International Partners became active participants in the Space Station Redesign Team (SRT).

Programmatic Assessment

The common position of the International Partners can be summarised as follows:

- Given the present constraints as regards budgetary guidelines and limitations on study options, we have serious concerns about the ability to meet the commitments in the IGA and MOU's for Space Station. Within these constraints the accommodation of our contributions is not achievable.

- All options must be implementable within the long term international cooperative framework established among the partners on the basis of genuine partnership and the provision by the International Partners of their own elements as their contribution to the building, in low earth orbit, of a permanently manned civilian space station.

- Transition to a new management regime, must provide for continuity with current program management to maximize the benefits of investments to date.

- It is essential that all options be assessed against broad and well-defined development and operations requirements including a utilisation scenario and that any changes to the current Space Station Freedom design be based on mature assessments of all parameters of importance, in particular requirements, cost and schedule.

- No systematic traceability to the current Space Station Freedom requirements baseline has yet been established, making it very difficult to make comparisons between the three redesign options and the current Space Station Freedom baseline in terms of capabilities and performances.

- The International Partners fully support the proposals made for reducing operations costs by reduction of planning manpower levels, simplification of training approach and consolidation of sustaining engineering effort. We recognise that this should result in benefits for all partners.

- The International Partners believe that further cost efficiencies could be achieved by a more optimised distribution of responsibilities, and a greater use of the partners' facilities as their contribution to common station operations costs.

- Offers of additional hardware and services, for example, the European offer to study the provision of the Data Relay Satellite (DRS), Assured Crew Return Vehicle (ACRV), Automated Transfer Vehicle (ATV) and Ariane launch services should be taken into account.

- Launching to a 51.6 degree inclination orbit has significant technical, programmatic and operational implications to the program, in particular with respect to:

  The need for enhanced shuttle performance for station assembly (ASRMs and Al-Li external tank), or downsizing of pressurized modules

  The increased number of station assembly and resupply flights with associated cost impacts.

- The International Partners fully support the objective to achieve multiple access, which is understood to be the main driver for this orbit. However, this can also be achieved at other inclinations by use of European and Japanese vehicles from their launch sites. Selection of orbital inclination should be based on optimisation of all factors involved with specific emphasis on minimisation of operations costs.

- It is recommended that NASA works together with the International Partners to maximise the benefits of a simplified DMS architecture for all options, whilst minimising the impacts to all partners.

- The proposed delivery schedules for partner provided elements is subject to further confirmation by each partner, following option selection and subsequent final assessment by each partner of the associated impacts on its respective programs.

Option Specific Assessments

Option A

- The overall configuration adequately accommodates the APM and the JEM. There is some reduction in continuous viewing capability for the JEM and APM Exposed Facilities. Crucial elements of the Mobile Servicing System have been deleted, including its Mobile Transporter, and significant changes have been made to its command and control system. Without a Mobile Transporter, the robotic arm must "walk" on the station, thereby significantly increasing the complexity of robotic assembly and maintenance activities. The shuttle manipulator arm is also being proposed for use in assembly tasks that are beyond its current design envelope.

- The proposed simplification of APM/JEM physical interfaces represents a significant potential improvement over the current baseline, with in particular, a reduction of EVA for APM/JEM assembly and simplification of interface verification.

- The stretched version of the Mini-Pressurised Logistics Module (MPLM), foreseen by this option, is considered feasible by ASI, and can be accommodated within the current ASI/NASA agreement. However, the proposed increase in the number of flight units, together with the provision of the MPLM derived "closet" module required by this option will have a major programmatic impact.

Option B

- For Option B which, like Option A, is a modular concept, the overall configuration is satisfactory. In all major respects this option is very close to the current Space Station Freedom and benefits from the maturity of this baseline.

Option C

- The US core module already provides more payload volume than the current SSF baseline, thus putting in question the real need for the additional payload volume provided by the International Partner modules. The

addition of these modules further reduces the availability of other critical payload resources such as power and heat rejection.

- The level of maturity of the Option C design is considered to be inadequate.
- The amount of new development associated with this option, including NSTS modifications, is considered to represent a high cost and schedule risk to the programme.
- The fire detection and suppression system does not seem to meet the safety requirements currently imposed on the baseline.
- The DMS and the Communications and Tracking system will have a significant impact on the partners' current contributions.
- Important elements of Canada's Mobile Servicing System have been deleted and their assembly and maintenance role is diminished. Provision for on-orbit maintenance of these manipulators has not been assured. New launch accommodations and a new end-to-end command and control system for the robots are required.
- The overall configuration and operational modes of Option C does not allow continuous zenith or nadir viewing from the JEM Exposed Facility, or from the APM Exposed Facility and calls into question the utility of this option as an observation platform.
- By providing accommodation for the centrifuge within the US Module, Option C excludes the potential to accommodate the ASI mini-lab.
- The identified need of a third MPLM flight unit will have a major programmatic impact for ASI.

Conclusion

The International Partners consider it mandatory that any international space station program resulting from this redesign exercise is one that can be implemented in line with the procedures laid down in the intergovernmental and agency to agency agreements. It should have the capacity to meet the objectives, and support the mission of the current International Space Station Freedom program. It should be affordable for all the partners, should be managed in a manner that ensures cost effective development as well as operation and utilisation, and it should provide all partners with benefits commensurate to their respective contributions.

Regardless of the redesign option selected, there is still much engineering work to be completed during the subsequent transition period. Consistent and detailed design and operations requirements have to be re-established and approved by NASA and the International Partners, as appropriate. The station assembly sequence up to, and including, assembly and outfitting of the International Partners' elements has to be analysed and verified. Planning for timely Space Station maintainability throughout its lifetime must be assessed.

A revised operations baseline has to be established with optimisation of all partner roles and responsibilities with NASA commitment to use partner capabilities, such as Ariane, ATV, ACRV, DRS, JDRS and H-II to offset common operations costs.

Launching the International Partners' modules on expendable launchers would require significant design modifications and would increase the partners' costs accordingly. Should this alternative be pursued, the partners' own launch capabilities will be considered first.

The International Partners' contributions to the common station operating costs should be fixed within a financial ceiling to be agreed.

Options A and B are both acceptable from an International Partner module accommodation and utilisation point of view. However, taking into account the doubts associated with the robotics aspects of assembly and maintenance of Option A, this option is considered to have a higher risk than Option B.

For Option C, the International Partners have strong reservations due to its lack of maturity. Furthermore, the loss of the essential role of the International Partners' modules renders this option unattractive with respect to their current contributions. The technical and programmatic uncertainties of Option C constitute a higher risk than the other options.

Any decision not to proceed, or to proceed with a space station in a manner that does not adequately accommodate the interests of all the partners, would result in a significant set-back for international collaboration in science and technology.

POTENTIAL COOPERATION WITH THE RUSSIANS

During the course of the redesign effort, NASA invited the Russian Space Agency and several Russian aerospace contractors to share their experiences with long-duration space flight and to assist in an assessment of the capabilities of their various hardware systems. Given the time constraints and our concentration on assessing the work of the Redesign Team and the international partners, only a few areas of possible cooperation with Russians were examined.

However, the Committee was able to identify two important areas where Russian cooperation would be beneficial: employing the Soyuz spacecraft as an assured crew return vehicle, and utilizing Russian launch vehicles and sites. The potential selection of a higher inclination orbit could enhance the opportunity for use of Russian space assets. For a discussion of these subjects, see the "General Mission Considerations" section.

The Committee also feels that the Russians have other important capabilities that could be advantageous to a redesigned space station. Among such assets are automated rendezvous and docking hardware, environmental control and life support systems, Mir, and other mechanical components.

These assets could be utilized in many different facets of the space station program. For example, Russian automated rendezvous and docking hardware would potentially permit the use of a common docking capability for both the Soyuz-Progress vehicles and for NASA's shuttle. With almost 20 years of experience, the Russian environment control and life support systems would help minimize electrical power requirements for the station. Finally, Mir offers another potential for early joint-nation cooperative research opportunities.

The Committee recommends that NASA and the Administration further pursue opportunities for cooperation with the Russians as a means to enhance the capability of the station, reduce cost, provide alternative access to the station, and increase research opportunities.

an associate professor of aeronautics at the U.S. Air Force Academy. He earned a B.S. in mechanical engineering from Washington State University, a M.S. in aerospace engineering from the Air Force Institute of Technology, and a Ph.D. from the University of Washington in aeronautics and astronautics. His decorations include the Defense Superior Service Medal, the Legion of Honor, and the NASA Space Flight Medal. Dr. Fabian is an Associate Fellow of the American Institute of Aeronautics and Astronautics, a member of the International Academy of Astronautics, and a trustee of the Washington State University Foundation. He is also a former president and current board member of the Association of Space Explorers. In 1986 he served on the President's Commission to Investigate the Space Shuttle Challenger Accident.

James A. Fain, Jr. In May 1993, Lieutenant General James A. Fain, Jr. became the Commander, Aeronautical Systems Center, Air Force Material Command, Wright-Patterson Air Force Base, Ohio. A command pilot and test pilot with more than 4,500 flying hours, he earned his wings in 1964 from Moody Air Force Base, Georgia. He then completed numerous B-52 flight assignments. In 1971 he entered the Air Force Test Pilot School at Edwards Air Force Base, California. Upon graduation in 1973, General Fain was assigned to the 13th Tactical Fighter Squadron,Udorn Royal Thai Air Force Base, Thailand, as an F-4 pilot. He returned to the U.S. in 1974 and served in various aspects of flight testing at Kirtland Air Force Base and back at Edwards. In 1981, General Fain became chief of Test and Integration for the LANTRIN program (Low Altitude Navigation and Targeting Infrared System for Night) at Wright-Patterson, and later became director of the Strike System Program Office. In 1992, the general became director of requirements, at Wright-Patterson's Headquarters Air Force Material Command. His military decorations include the Legion of Merit, Meritorious Service Medal with oak leaf cluster, Air Medal with two oak leaf clusters, and Air Force Commendation Medal with oak leaf cluster. He earned a bachelor's degree in engineering from the U.S. Air Force Academy and a master's degree in systems management from the University of Southern California.

Edward B. Fort. Since 1981, Dr. Fort has served as the Chancellor of North Carolina A & T State University in Greensboro. Under his leadership, the University's School of Engineering has become the nation's number one producer of black engineers at the Master's degree level. In addition, he was a leader in the negotiation of a joint venture with NASA and North Carolina State University to establish the MARS Space Research Center. The University has also been designated as a NASA Center for Engineering Excellence. During his education career Dr. Fort has served as the Chancellor of the University of Wisconsin System Center, Superintendent of Schools in Sacramento, California and in Inkster, Michigan, Adjunct Professor of Administration at the University of Michigan, and Visiting Professor at the University of Detroit. Dr. Fort received a Bachelor's, Master's, and an Honorary Doctorate of Law at Wayne State University. He earned his Ph.D. from the University of California-Berkeley. He is currently a member of NASA's Advisory Council, the President's Advisory Board on Historically Black Colleges and Universities, the Biotechnology Board of North Carolina, and the International Association of University Presidents. Dr. Fort is also Chair of the Advisory Committee on Educational Opportunities and Achievement of the American Association of State Universities and Colleges.

Dr. Mary Lowe Good. Dr. Good has been associated with Allied Signal Inc. since 1985 and currently serves as the Senior Vice President for Technology. From 1980 to 1985, she was Vice President-Director of Research at UOP, Inc. Dr. Good came to private industry from the academic community where she was the Boyd Professor of Materials Science at Louisiana State University and the Boyd Professor of Chemistry at the University of New Orleans. She served as a member of the President's Council of Advisors on Science and Technology, as well as the National Science Board including terms as Vice Chairman and Chairman. She is a member of the Council of the National Academy of Engineering and serves on the Joint High Level Oversight Advisory Panel to the United States-Japan Agreement on Cooperation in Research and Development in Science and Technology. Dr. Good is also a member of NASA's Space Systems and Technology Advisory Committee and sits on the Board of Directors of Cincinnati Milacron Inc. and Ameritech. Additionally, Dr. Good is on the Board of Trustees of Rensselaer Polytechnic Institute. The author of <u>Integrated Laboratory Sequence: Volume III -Separations and Analysis</u>, Dr. Good has written more than 100 technical publications and articles on science policy and research management. She received a B.S. in chemistry from the University of Central Arkansas and her M.S. and Ph.D. in chemistry from the University of Arkansas. Dr. Good's contributions to her field have earned her numerous awards, including the National Science Foundation Distinguished Public Service Award, the Industrial Research Institute Medalist Awards, and the American Association for the Advancement of Science Award.

Louis J. Lanzerotti. Dr. Lanzerotti has been involved in geophysics and space physics research since he joined AT&T Bell Laboratories in 1965, where he is presently a Distinguished Member of Technical Staff. He is also an Adjunct Professor in Electrical Engineering at the University of Florida. Dr. Lanzerotti has served on numerous government science committees, including the NASA Advisory Council, Chairman of NASA's Space and Earth Science Advisory Committee, the Advisory Committee on the Future of the U.S. Space Program, and the Space Studies Board of the National Research Council; he is currently Chairman of the Council's Space Studies Board. He has received NASA's Distinguished Public Service Medal. He has been elected to membership in the National Academy of Engineering and the International Academy of Astronautics. He is a Fellow of the American Association for the Advancement of Science, the American Geophysical Union, and the American Physical Society. Dr. Lanzerotti's research activities focus on planetary magnetospheres, energetic particles emitted by the Sun, and the impacts of space processes on space and terrestrial technologies. Dr. Lanzerotti served as an elected member of the Harding Township, NJ School Board from 1982–1990, and is presently an elected Committeeman on the Township's governance body. He received an undergraduate degree in engineering from the University of Illinois and his A.M. and Ph.D degrees in physics from Harvard. Dr. Lanzerotti has reported on his research in 300 technical articles and is coauthor or coeditor of three books.

William E. Lilly. Mr. Lilly is an independent consultant currently working with the National Academy of Public Administration. In performing studies for the Academy he specializes in aerospace and aeronautical management issues. Examples of the projects he has completed for the Academy include the Study of the Cost and Financing of the Commercially Developed Space Facility," and a "Review of the Centers for the Commercial Devel-

opment of Space: Concept and Operations." Mr. Lilly retired from NASA in 1981 following a government career that also included service in the Department of the Navy, and the National Bureau of Standards. From 1967 until the time of his retirement, he was the Comptroller at NASA Headquarters responsible for the planning, analysis, and control of the total agency resources. While with NASA he also served as the Assistant Administrator for Administration and was the Director of Program Control for the Office of Manned Space Flight during the development of the Mercury, Gemini, and Apollo programs. Mr. Lilly was awarded two NASA Distinguished Service Medals, two NASA Exceptional Service Medals, and two Executive Performance Awards. Additionally, he was designated with the Presidential Rank of Distinguished Executive. He received a B.S. degree in public administration and completed a year of graduate work in public administration at the University of California-Berkeley.

Duane T. McRuer. Mr. McRuer is the President and Technical Director of Systems Technology, Inc., an engineering consulting firm he cofounded in 1957. As a prime contractor and consultant to the U.S. government and private industry, Systems Technology, Inc. conducts research and development programs in terrestrial, astronautical, and aeronautical vehicle dynamics, guidance and control systems, human operator dynamics, and associated topics. Mr. McRuer's research on control systems engineering has led to five patents. He is a member of the National Academy of Engineering and has served as a member and Chairman of the National Research Council's Aeronautics and Space Engineering Board, and as a member of the Council's Committee on Human Exploration of Space. He currently serves on the NASA Advisory Council and has participated on Committees involving aeronautics, space station engineering design issues, and the Commercially Developed Space Facility. Mr. McRuer is a Fellow of five professional societies, including the American Association for the Advancement of Science, the American Institute of Aeronautics and Astronautics, the Institute of Electrical and Electronic Engineers, the Human Factors and Ergonomics Society, the Society of Automotive Engineers, and the American Association for the Advancement of Science. He has written seven books, including *Aircraft Dynamics and Automatic Control*, and *Analysis of Nonlinear Control Systems* published widely in his field and has written two books on aircraft dynamics and on nonlinear control systems. He is a Distinguished Alumnus of the California Institute of Technology, where he received a B.S. in engineering and an M.S. in electrical engineering.

George D. Nelson. A former NASA astronaut, Dr. Nelson participated in three space shuttle missions, including a spacewalk to retrieve and repair a space science satellite. He is currently affiliated with the University of Washington where he serves as the Assistant Provost, Associate Professor of Astronomy and of Education, and as Associate Director of the Washington Space Grant College Program. Before joining the astronaut corps in 1978, Dr. Nelson was a Research Associate at the Joint Institute for Laboratory Astrophysics and had been an astronomer at the University of Gottingen in Germany and the University of Utrecht in the Netherlands. He graduated from Harvey Mudd College with a B.S. in physics with honors and distinction, and received an M.S. and Ph.D. in astronomy from the University of Washington. Dr. Nelson serves as a trustee of the Analytical Services, Inc. and is on the Board of Directors of the Art Institute of Seattle,

the Association of Space Explorers, and the Washington State Biotechnology Association. He has served on NASA Task Forces on Space Station Freedom Operations and on the Space Telescope Repair Mission, and was a technical advisor to the both the Synthesis Group on America's Space Exploration Initiative and the National Commission on Space. Dr. Nelson was selected as a Fellow of the American Council on Education and received the Haley Space Flight Award from the American Institute of Aeronautics and Astronautics. His awards from NASA include the Exceptional Engineering Achievement Medal, the Exceptional Service Medal, and three Spaceflight Medals.

Bradford W. Parkinson. The original program director of the Defense Department's Global Positioning Satellite system, Dr. Parkinson has a broad background in guidance, control, astrodynamics, simulation, avionics, navigation, and software engineering. He is currently a professor of aeronautics and astronautics at Stanford University where he also functions as the Program Manager of the NASA Gravity Probe B spacecraft intended to verify Einstein's Theory of General Relativity.
Dr. Parkinson is also leading a Stanford research group that is developing innovative uses of the Global Positioning Satellite for aviation applications. He is a distinguished graduate of the Air Command and Staff College and the U.S. Naval War College. He graduated with a B.S. in engineering from the U.S. Naval Academy and received his M.S. and Ph.D. in aeronautics and astronautics from the Massachusetts Institute of Technology and Stanford. Dr. Parkinson was elected to the National Academy of Engineering and is a Fellow of the Royal Institute of Navigation and the American Institute of Aeronautics and Astronautics. He was awarded the Royal Institute of Navigation's Gold Medal and has received the Kirschner Award from the Institute of Electrical and Electronic Engineers.
Dr. Parkinson has authored more than 50 papers on the subjects of guidance, navigation, and control.

Robert C. Seamans, Jr. Dr. Seamans is a Senior Lecturer in the Department of Aeronautics and Astronautics at the Massachusetts Institute of Technology. During his professional career, he has served in numerous senior level positions in the government, including Associate Administrator and Deputy Administrator of NASA, Secretary of the Air Force, and the first Administrator of the Energy Research and Development Administration.
Dr. Seamans is actively involved on the governing boards of a number of professional societies and institutions including the Boston Museum of Science, the National Geographic Society, the New England Medical Center, Woods Hole Oceanographic Institution, and the Carnegie Institution of Washington. He has served as the President of the National Academy of Engineering, chaired the National Research council's Committee on the Space Station, was Vice Chairman of the Steering Committee for NASA's Synthesis Group on the Space Exploration Initiative, and is the Chairman Emeritus of the NASA Alumni League. Among his many honors are the Robert H. Goddard Memorial Trophy, NASA's Distinguished Service Medal, the Department of Defense Distinguished Public Service Medal, and the USAF Space Trophy. Dr. Seamans is a graduate of Harvard and received an M.S. and Doctor of Science degree from the Massachusetts Institute of Technology.

Leon T. Silver. Dr. Silver is the W.M. Keck Foundation Professor for Resource Geology at California Institute of Technology. Among his principal research interests are the understanding of natural

resources in relation to continental evolution, tectonics of western America and Mexico, and petrology of meteorites and planetary evolution. He is Past President and a Fellow of the Geological Society of America, and a fellow of the Mineralogical Society of America, and the American Association for the Advancement of Science. Dr. Silver was elected to the National Academy of Sciences and served as a member of the Council of the Academy and on the governing Board of the National Research Council. He serves as the Chairman of the Advisory Committee to the Office of Basic Energy Sciences of the Department of Energy and was a member of the Steering Committee of the NASA Synthesis Group which evaluated mission scenarios for the President's Space Exploration Initiative. During the Apollo program, Dr. Silver played a major role in instructing the astronauts in lunar geology, as well as designing several surface geology experiments. Dr. Silver received the Award for Professional Excellence from the American Institute of Professional Geologists, and was presented with NASA's Exceptional Service Medal. His undergraduate and graduate degrees are in civil engineering and geology, and he received a Ph.D. in geology and geochemistry from the California Institute of Technology.

Albert D. Wheelon. In 1988, Dr. Wheelon retired as the Chief Executive Officer and Chairman of the Board of the Hughes Aircraft Company. He is a trustee of the California Institute of Technology, The Aerospace Corporation, and The Rand Corporation. Dr. Wheelon also participates on committees involving the government's national laboratories including the University of California President's Council on the National Laboratories, the Director's National Security Advisory Board for Los Alamos National Laboratory, and the Director's Advisory Committee of the Lawrence Livermore National Laboratory. He also serves on the Board of Overseers for the Superconducting Supercollider Project. From 1983–1988 he was a member of the President's Foreign Intelligence Advisory Board. In 1986 he was a member of the Presidential Commission to Investigate the Space Shuttle Challenger Accident. Dr. Wheelon was the Deputy Director for Science and Technology of the Central Intelligence Agency from 1962–1966. He is a Fellow of the Institute of Electrical and Electronics Engineers and the American Institute of Aeronautics and Astronautics. He was also elected to the National Academy of Engineering, and the Council on Foreign Relations. He earned an undergraduate degree in engineering from Stanford and a Ph.D. in physics from the Massachusetts Institute of Technology.

Biographies of Ex Officio Members

Karl H. Doetsch. As Director General of the Space Station program in the Canadian Space Agency, Dr. Doetsch is responsible for Canada's contribution of the Mobile Servicing System to the international space station program. He has followed a varied career in the aerospace sector, both in aeronautics and in space flight. He was the final project manager on the orbiter's remote manipulator system, Canadarm, the first Director of Canada's astronaut program, and Associate Director of the National Aeronautical Establishment of the National Research Council. He is a Fellow and former president of the Canadian Aeronautics and Space Institute , a Fellow of the Canadian Academy of Engineering, and a Vice President of the International Astronautical Federation. He has been a recipient of the Royal Society of Canada Thomas Eadie Award and the NASA Public Service Award. Dr. Doetsch received his

bachelor of science degree in engineering, and his DIC and Ph.D. from Imperial College, London University.

Fredrik Engstrom. Born Karlskrona, Sweden, in 1939, Fredrik Engstrom received his Masters Degree in 1964 and his Doctorate in 1971 from Stockholm University. He started his career as Project Manager with the space Technology Group, where he was mainly involved in managing sounding rocket launchings. Between 1965 and 1970 he was an European Space Research Organization Fellow at Culham Laboratories, and a Research Assistant at the Stockholm where he was involved in space projects. During his term of office, from 1972 to 1985, as President of the Swedish Space Corporation he was behind the decision to undertake the first Swedish satellite project, Viking, and later, the Nordic Spacecraft Tele-X, for direct broadcasting and business communications. He was also a Board member of the Kiruna Geophysical Institute. It was largely due to his initiative that a daughter company of the Swedish Space Corporation, the Satellite Image Corporation in Kruna, was set in 1982. In parallel with his activities as president of the Swedish Space Corporation, he was also Chairman of the Board of the daughter company until 1985. Dr. Engstrom has been closely linked with the European Space Agency prior to his appointment in 1985: From 1977 to 1979 he was Chairman of ESA's Remote Sensing Programme Board and from 1979 to 1985 Swedish Delegate to the Agency's Council.

Luciano Guerriero. Professor Guerriero has been the President of the Italian Space Agency (ASI) since 1988. Previously, since 1980, he had the responsibility of the Italian National Space Program (PSN/CNR). In this framework he developed several space projects in cooperation with other space agencies and, in particular, with NASA. At present, he is also the head of the Italian delegation of the European Space Agency (ESA). During his professional career, he has been leading Italian research groups as part of large international cooperations in the field of High Energy Particle Physics conducting experimental activities at Padua and Bari Universities in Italy and at national and international laboratories such as Brookhaven National Laboratory, Fermi Lab, and CERN. Since 1968 he has been a full professor of General Physics at Bari University, where he has been Director of the Physics Department. He has also served in numerous government committees in Italy in particular as Vice-President of the Italian National Institute for Nuclear Physics (INFN) and as Director of the Institute for Signal and Image Processing of the Italian National Research Council.

Shigebumi Saito. Dr. Saito was born in Tokyo, Japan, on September 17, 1919. He received his bachelor degree in 1941, and a Ph.D. in Electrical Engineering in 1951 from the University of Tokyo. During World War II, he did research on microwave radar systems for the Naval Technical Institute of Japan and was appointed as an associate professor at the University of Tokyo in 1947. Dr. Saito conducted research at the Massachusetts Institute of Technology as a Fulbright Fellow, where he worked on the measurement of electron-beam noise and VHF low-noise tubes. He later returned to the University of Tokyo and was engaged in research on microwave and laser applications to the electronics field. He was also a professor at the Institute of Space and Aeronautical Science. Dr. Saito served as the Director, the National Space Development Agency (NASDA) of Japan from 1969 to 1974, and was appointed as a member of the Space Activities Commission of Japan. He retired from the University of Tokyo in 1980 where he retains

the titled as professor emeritus. He was then promoted as Commissioner of the Space Activities Commission of Japan, and later appointed High Commissioner, a position he held until 1991. Dr. Saito is a member and a past Chairman of the Radio Technical Council, and is the Chairman of the Telecommunications Technology Council. Since 1991 he has been the Chairman of Japan International Space Year (ISY) Association. He has served as the Vice President of the International Astronautical Federation and was also the President of the Institute of Electronics and Communication Engineers of Japan. He is a Fellow of the Institute of Electrical and Electronics Engineers and served as served of the Editorial Board of the IEEE's Spectrum magazine. Among his many honors , Dr. Saito received the Commendation Award from Minister of Posts and Telecommunications, the Imperial Award from the Japan Institute of Invention and Innovation, the Distinguished Service Award from the Institute of Electronics and Communication Engineers of Japan, the Prime Minister's Award of World Communications Year, the NHK Broadcasting Culture Award, and the Imperial Purple Ribbon Medal. He also received the Telecom Week Award from Minister of Posts and Telecommunications, and was decorated the Order of the Sacred Treasure, Gold and Silver Star.

Special Assistants to the Advisory Committee

Virginia E. Durgin. Ms. Durgin is a Group Chief for the Central Intelligence Agency responsible for contracting activities and the career development of procurement professionals. She serves as a member of the Agency's Procurement Policy Panel. Prior to returning to the Central Intelligence Agency in 1982, she served as Contracts Manager for the Western Union telegraph Company, and as Director of Contracts for Xontech. Ms. Durgin received her bachelor's degree from Asbury College, Wilmore, Kentucky and did graduate work at Ohio State University and at California State University.

Mark Werfel. Mr. Werfel began his career as Presidential Management Intern, and has worked for each military department in a progressive series of operational and Headquarters positions. He currently serves as a U.S. Army information systems acquisition manager. He has been responsible for the resolution of many of the major contracting issues of the past decade, such as shipbuilding claims, spare parts pricing, defense industrial modernization incentives and improving the focus of Government acquisition organizations on its customers needs. Mr. Werfel is a 1985 graduate of the Air War College resident program, and holds a Bachelors Degree in Economics from Brooklyn College and a Masters Degree in Business Administration from Troy State University. His position on defense industrial base policy was published in "Defense News" on June 14, 1993.

Committee Support

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APPENDIX B

White House Budget Target Summary

April 3, 1993

Space Station Development Budget Options 1994–1998

Option 1: $5 billion total (1994–1998)
$1.0 billion peak annual funding (1995–1998)

Option 2: $7 billion total (1994–1998)
$1.5 billion peak annual funding (1995–1998)

Option 3: $9 billion total (1994–1998)
$1.8 billion peak annual funding (1995–1998)
(To meet the President's new technology investment goals, this option would require NASA to propose $2 billion in reductions from the remainder of its 1994–1998 budget.)

The budget totals include:

- Development
- Operations
- Utilization
- Facilities
- Shuttle integration
- Research operations support
- Transition costs
- Enhanced early flight research
- Adequate program reserves

The budget totals do not include shuttle operations and civil service salaries and related support costs.

APPENDIX C

EXECUTIVE OFFICE OF THE PRESIDENT
OFFICE OF SCIENCE AND TECHNOLOGY POLICY
WASHINGTON, D.C. 20506

April 30, 1993

Dear Chuck:

Thank you for your letter of April 9 requesting a statement of the Administration's first-level objectives for the space station and its strategic goals for the civil space program. I have attached our first-level objectives for the space station and look forward to discussing them with you and hearing how they were received by the Advisory Committee. As the Administration is currently formulating its strategic goals for the civil space program, I am not able to send you a definitive answer to that question. I would like, however, to share with you some preliminary observations on the subject.

The President's 1994 budget demonstrates this Administration's strong commitment to the civil space program. In the future, we will work to ensure that all the resources dedicated to the civilian space program are well-managed and focused on issues that are critical to the nation. First, the space program should create new knowledge that will contribute to our understanding of our environment and of our place in the universe. Space systems, with their unique vantage point, provide an indispensable tool for understanding how human actions influence the complex workings of our planet. Similarly, space science and robotic planetary exploration can provide us with otherwise unobtainable knowledge and insights regarding both our home planet and the universe in which we live. Research that expands the bounds of our technology can also provide new capabilities that contribute to our economic strength.

The space program can also make an important contribution to the U.S. economy. Prudent, industry-led investments in aeronautics and space research can provide important assistance to the aerospace industry and to other industries, which can, in turn, make significant contributions to the U.S. economy. For example, past government/industry cooperation in aeronautics and in satellite communications has helped to achieve and sustain U.S. leadership in these critical areas.

International cooperation in space activities can help the international community move beyond the Cold War. Working with our existing partners in Europe, Japan, and Canada, and with Russia and other parts of the emerging democratic world, we can forge additional relationships that contribute to global peace and prosperity. International cooperation in space science, exploration, and commerce can provide an important lesson on how nations, working together, define challenges and solve problems that no one nation alone could accomplish.

The space program also has an important role in helping to generate and sustain interest in math and science education. The excitement generated by the space program can be used to interest young people in math and science education. This interest can not only help create the scientists, engineers, and educators that are the key to the future economic competitiveness of our nation, but also increase the understanding of science and technology by tomorrow's adults -- a critical need for the continued strength of our democracy.

Finally, human space flight is and will continue to be a significant element of our domestic and international space program. Humans can make a unique contribution, as part of a balanced program of robotic and human exploration, to our scientific and technical knowledge, as well as our understanding of the benefits and limitations of humans living and working in space.

I hope these brief thoughts will be useful in helping you to focus your work. I look forward to discussing these issues with you and to receiving the final guidance from the Advisory Committee.

Sincerely,

John H. Gibbons
Director

Dr. Charles M. Vest
President
Massachusetts Institute of Technology
77 Massachusetts Avenue
Cambridge, Massachusetts

Attachment

cc: Greg Simon
Bowman Cutter
Leon Panetta

SPACE STATION PROGRAM OBJECTIVES

- **Create the capability to perform significant long-duration space research in materials and life sciences:**

  - As measured by, for instance: power and other resources available to payloads; experimental racks and other user equipment; crew time for research activity; microgravity level; experiment duration; and utility for research between crew visits.

- **Develop the technology and the engineering skills necessary to build and operate advanced human and autonomous space systems:**

  - The construction of the space station is an engineering and technology development effort that provides a worthy challenge for our national technical talents.

- **Encourage international cooperation in science and technology:**

  - Retain participation by the current international partners; consider, but not limit, redesign options to those accommodating Russian participation.

- **Provide opportunity for new users, particularly industry users, to conduct experiments on new, commercially relevant products and processes;**

  - Fully utilize existing aerospace industry capabilities and products where sensible; ease entry by non-traditional space users.

- **Acquire new knowledge regarding the feasibility and desirability of conducting human scientific, commercial, and exploration activities:**

  - The value of future commercial and scientific space station facilities and the practicality of the future human exploration of the solar system depends, in large measure, on the effectiveness of humans in space, and on the effect that long-term presence in space will have on their health and their capabilities.

APPENDIX D

Space Station Capabilities Matrix

RESEARCH RESOURCE PARAMETERS													
PARAMETERS	UNITS	REQUIREMENT	OPTION A1				OPTION B				OPTION C		
28.8 DEGREE INCLINATION		(REQ REF)	PS	HTC	IHTC	PHC	PS	HTC	IHTC	PHC	PHPC	IPHP	PHC
CREW AND DURATION													
TOTAL NUMBER OF CREW	#	3,4(3.4,4.4)	4	4	4	4	4	4	4	4	4	4	4
TOTAL NUMBER OF RESEARCH CREW	#	2(1.1)	3+	3	3	3+	3+	3	2+	3+	3+	3+	3+
MAXIMUM CONTIGUOUS ON-ORBIT DAYS	DAYS	90(1.1)	20	20	20	365	20	20	20	365	365	365	365
TOTAL CREWED DAYS/YEAR	DAYS/YR		40	80	80	365	40	80	80	365	365	365	365
TOTAL AVAILABLE CREWHOURS/YEAR	HRS/YR		960	1920	1920	7680	960	1920	1920	7680	7680	7680	7680
TOTAL SYSTEMS CREWHOURS/YEAR	HRS/YR		50	415	476	956	50	471	550	1114	706	796	814
TOTAL RESEARCH CREWHOURS/YEAR	HRS/YR		910	1505	1444	6724	910	1449	1370	6566	6974	6884	6866
POWER ([illegible])											*	*	*/**
TOTAL POWER AVAILABLE (ORB AVG)	KW		23.1	23.1	46.1	57	23.5	23.5	68.3	68.3	57.6/34.2	57.6/34.2	75.6/46.5
SYSTEMS POWER (ORB AVG)	KW		15	16.1	28.1	26	11.4	15	27.7	28	10	20.4	20.4
USER POWER (ORB AVG)	KW	30(1.2)	8.1	7	18	31	12.1	8.5	40.6	40.3	47.6/24.2	37.2/13.8	55.2/26.1
30 DAY MAX. CONTINUOUS POWER	KW		18.5	18.5	39	45.8	19	19	59	59	54/29	49/29	57/37
MAX. POWER TO SINGLE P/L @ μg<1	KW	12(1.3)	4.5(SL)	7	12	12	4.5(SL)	8.5	12	12	12	12	12
VOLUME/RACKS													
TOTAL PRESSURIZED VOLUME	CUB M		93(SL)	110	491	760	93(SL)	219	680	878	736	1117	1117
SYSTEM RACKS	#		2(SL)	7	31	59	2(SL)	11	41	65	24.5	50.5	50.5
USER RACKS	#	35 W/ IP(1.5)	8(SL)	9	39	39	8(SL)	16	48.5	45.5	40	72	72
UNITED STATES USER RACKS	#	11 @ HTC(1.5)	8(SL)	9	23	23	8(SL)	16	31	28	40	54	54
CENTRIFUGE ACCOMM. W/IN VOLUME	Y/N- SIZE	YES-1.8M(1.6)	NO	NO	NO	YES-2.5	NO	NO	NO	YES-2.5	YES-2.5	YES-2.5	YES-2.5
MICROGRAVITY LEVELS													
USER RACKS @<1μg	#****	PDRD(1.8)	7(SL)	9/0	29/0	8	4(SL)	0/16	21/16	29/13	30	40	40
USER RACKS @<2μg	#****	PDRD(1.8)	8(SL)	9/0	39/14	36	8(SL)	10/16	38/31	45/28	40	72	72
OCCUPIED 30 DAY PERIODS AT LVLH	#		0	0	0	12	0	0	0	12	12	12	12
ENVIRONMENT & CREW HEALTH				*****	*****	*****	*****	*****	*****	*****	*****	*****	*****
OXYGEN LEVEL	%	21(1.7,2.15)	21(ORB)	21	21	21	21(ORB)	21	21	21	21	21	21
CO2 LEVEL	%	0.3	0.7(ORB)	0.52	0.52	0.6	0.7(ORB)	0.52,0.76	0.52,0.76	0.52	0.6	0.6	0.6
RELATIVE HUMIDITY	%	30-70(*)	30(ORB)	25-70	25-70	25-70	30(ORB)	25-70	25-70	25-70	30-70	30-70	30-70
CABIN PRESSURE	PSIA	14.7(*)	14.7(ORB)	14.7	14.7	14.7	14.7(ORB)	14.7	14.7	14.7	14.7	14.7	14.7
COMMUNICATIONS													
COMMUNICATION BANDS	TYPE		S	S, Ku	S, Ku	S, Ku, UHF	S	S, Ku	S, Ku, UHF	S, Ku, UHF	S, Ku	S, Ku	S, Ku
COMMUNICATION UPLINK	BPS	72K(1.17)	S-72K	S-72K			S-72K	S-72K			S-72K		
COMMUNICATION DOWNLINK	BPS	50M((1.15)	S-192K	S-192K, Ku-50M			S-192K	S-192K, Ku-50M			S-192K, Ku-50M		
VIDEO UPLINK/DOWNLINK	#CHANNELS	1/1(1.14/16)	0/0	0/4	0/4	0/4	0/0	0/4	0/4	0/4	0/2	0/2	0/2
VIDEO DOWNLINK COMPRESSION	#CHANNELS	6(1.14)	0	4	4	4	0	0	0	0	0	0	0
DATA MANAGEMENT													
P/L DATA MANAGEMENT COMPUTER	Y/N	YES(1.11)	YES(SL)	YES	YES	YES	YES(SL)	YES	YES	YES	YES	YES	YES
ON BOARD DATA STORAGE	MBYTES		40	120	120	120	640	1280	1280	1280	441	441	441
TOTAL LINES OF CODE (NOT INCL. I.P.)	#		232K	405K	435K	492K	431K	1220K	1220K	1372K	232K	232K	232K
EXTERNAL/VIEWING PAYLOADS													
EXTERNAL SITES	#	4(1.2)	4	10	17	21	1	2	15	15	4	14	14
EXTERNAL PAYLOAD POINTING	DIRECTION	N,R,W,Z(1.23)	N,R,W,Z	N,R,W,Z	N,R,W,Z	N,R,W,Z	N,R	N,R,W,Z	N,R,W,Z	N,R,W,Z	N,R,W,Z	N,R,W,Z	N,R,W,Z
OPTICAL WINDOWS	#-SIZE	1-20"(1.27)	0	1-8"	1-8"	1-8"	0	1-8"	1-8"	2-8"	4-8"	4-8"	4-8"
										2-20"	2-20"	2-20"	2-20"
GROWTH POTENTIAL													
TOTAL CREW	#	8(GG10,4.5)				8				8			8
TOTAL POWER	KW	75(GG10,4.5)				68				75			75
NOTES:													
*Solar Inertial/LVLH		***Does not include ACRV		*****0.3% CO2 is achievable on a periodic basis as required									
** Power regulation to 123+/-03V on some channels		****Without/With the Orbiter											

ASSEMBLY, OPERATIONS AND SAFETY PARAMETERS

PARAMETERS	UNITS	REQUIREMENT	OPTION A1				OPTION B				OPTION C		
28.5 DEGREE INCLINATION		(REQ REF)	PS	HTC	IHTC	PHC	PS	HTC	IHTC	PHC	PHPC	IPHP	PHC
ASSEMBLY													
CUMM.ASSEMBLY/OUTFITTING FLIGHTS	#		3	5	12	16	2	8	17	20	3	9	10
LAUNCH VEHICLE	TYPE		SHUTTLE	SHUTTLE	SHUTTLE	SHUTTLE	SHUTTLE	SHUTTLE	SHUTTLE	SHUTTLE	SLCS/SH	SHUTTLE	SHUTTLE
CUMMULATIVE ASSEMBLY EVA	MANHRS		40	64	154	224	44	159	294	311	0	12	24
OPERATIONS													
NUMBER OF LOGISTICS FLIGHTS	FLTS/YR		0-1	1-2	2-3	6*	0-1	1-2	1-2	6*	5	6*	6*
OPERATIONS CREW HOURS	MANHRS/YR		14	122	134	226	14	122	134	226	226	249	249
MAINTENANCE CREW HOURS EVA/IVA	MANHRS/YR		36/0	125/168	143/199	187/543	36/0	175/174	193/223	253/635	50/430	68/479	80/485
ORBITER MATING CAPABILITY	SNGL/DUAL	DUAL(2.23)	SINGLE	SINGLE	SINGLE	DUAL	SINGLE	DUAL	SINGLE	SINGLE	DUAL	DUAL	DUAL
MOBILE TRANSPORTER	Y/N		NO	NO	NO	NO	YES	YES	YES	YES	NO	NO	NO
ON-ORBIT DATA DISPLAY	Y/N	YES(3.5)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
PAYLOADS OPERABLE UNOCCUPIED	Y/N		YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
STATION OPERABLE UNOCCUPIED	Y/N		YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
SAFETY													
SAFE HOLD	YRS	2(2.29)	3	3	3+	3+	2+	2+	2+	2+	2	2	2
SAFE HAVEN	TYPE		N/A	N/A	N/A	ACRV	N/A	N/A	N/A	NODES	ACRV	ACRV	ACRV
CREW ESCAPE	Y/N	YES(2.8)	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
ACRV	#-TYPE	(2.8)	1-ORBITER	1-ORBITER	1-ORBITER	2-SOYUZ	1-ORBITER	1-ORBITER	1-ORBITER	2-SOYUZ	2-SOYUZ	2-SOYUZ	2-SOYUZ
FIRE DETECTION	AUTO/MAN	(2.7)	AUTO(ORB)	AUTO	AUTO	AUTO	AUTO(ORB)	AUTO	AUTO	AUTO	AUTO	AUTO	AUTO
FIRE SUPRESSION	AUTO/MAN	(2.7)	MAN(ORB)	AUTO/MAN	AUTO/MAN	AUTO/MAN	MAN(ORB)	AUTO/MAN	AUTO/MAN	AUTO/MAN	AUTO/MAN	AUTO/MAN	AUTO/MAN
STAN. CAUTION AND WARNING SYS.	Y/N	YES(1.13,2.6)	YES(ORB)	YES	YES	YES	YES(ORB)	YES	YES	YES	YES	YES	YES
CREW MANUAL OVERRIDES OF CRIT. SYS.	Y/N	YES(2.5)	YES(ORB)	YES	YES	YES	YES(ORB)	YES	YES	YES	YES	YES	YES
NOTES													

*Logistics flights reduce by one flight per year when the ASRM becomes available

	INTERNATIONAL PARAMETERS							
PARAMETERS	UNITS	REQUIREMENT	OPTION A		OPTION B		OPTION C	
28.8 DEGREE INCLINATION		REQ (PARA)	IHTC	PHC	IHTC	PHC	IPHP	PHC
JEM ACCOMMODATION								
COST/SCHEDULE								
DEVELOPMENT COST ADHERENCE	H/M/L	HIGH	M	M	M	M	L	L
OPERATIONS COST SAVINGS	H/M/L	HIGH	H	H	M	M	M	M
SCHEDULE ADHERENCE	H/M/L	HIGH	H	H	M	M	L	L
RESOURCE INTEGRITY								
SYSTEM POWER (CREW/NO CREW)	kW/kW	5.7/4	5.7/4	5.7/4	5.7/4	5.7/4	5.7/4	5.7/4
USER POWER (MAX./YEARLY AVG.*)	kW/kW	14/3.84	14/2.9	14/4	14/3.8	14/4.9	14/2.5	14/2.5
JEM RACKS (TOTAL/RACKS @ <1μg)	# / #	10/5	10/5	10/5	10/5	10/5	10/1	10/1
JEM EF P/L (TOTAL/SITES @<1μg)	# / #	10/5	10/2	10/2	10/5	10/5	10/1	10/1
DATA COMM. (UPLINK/DOWNLINK)	KBPS/MBPS	72/50	72//50	72/50	72/50	72/50	72/50	72/50
SYSTEM INTEGRITY								
MODULE INTEGRITY	H/M/L	HIGH	M	H	H	H	L	L
APM ACCOMMODATION								
COST/SCHEDULE								
DEVELOPMENT COST ADHERENCE	H/M/L	HIGH	M	M	H	H	L	L
OPERATIONS COST SAVINGS	H/M/L	HIGH	H	H	M	M	M	M
SCHEDULE ADHERENCE	H/M/L	HIGH	H	H	M	M	H	H
RESOURCE INTEGRITY								
SYSTEM POWER (CREW/NO CREW)	kW/kW	5.9/3.7	5.9/3.7	5.9/3.7	5.9/3.7	5.9/3.7	3/3	5.9/3.7
USER POWER (MAX./YEARLY AVG.*)	kW/kW	12/3.84	/3.6	12/3.84	12/3.84	12/3.84	/2.4	12/3.84
RACKS (TOTAL/RACKS @ <7μg)	# / #	21/11	11/11	11/11	11/11	11/11	11/11	11/11
DATA COMM. (UPLINK/DOWNLINK)	KBPS/MBPS	72/50	72/50	72/50	72/50	72/50	72/50	72/50
SYSTEM INTEGRITY								
MODULE INTEGRITY	H/M/L	HIGH	M	H	M	H	L	L
MSS ACCOMMODATION								
PROGRAM COMPLIANCE								
COMPLIANCE WITH BASELINE	H/M/L	SSP30000	M	M	H	H	L	L
COST COMPLIANCE	H/M/L	$1.35B	L	L	M	M	L	L
SCHEDULE COMPLIANCE	MONTHS	8/96						
MSS/USER RESOURCES								
MSS MAINTENANCE FEASIBILITY	YES/NO		NO	NO	YES	YES	NO	NO
POWER(PEAK/KEEPALIVE)	kW	5.4/1.2	5.4/1.2	5.4/1.2	5.4/1.2	5.4/1.2	TBD	TBD
PAYLOAD RACKS	#	1.5	1.5	1.5	1.5	1.5	1.5	1.5
CREW ALLOCATION	MO/YR	1.5+	1.5	1.5	1.5	1.5	1.5	1.5
SUBSYS. INTERFACE COMPLIANCE								
MSS-TO-P/L INTERFACE	H/M/L	SSP42004	M	M	H	H	M	M
CSA/NASA DESIGN RESPONSIBILITY	+ / -	SSP30651	+CSA	+CSA			+CSA	+CSA

APPENDIX E

Glossary of Cost Terms

Funding Lines for the Redesign Options

ACRV (Assured Crew Return Vehicle)

Provision of ACRV's to enable crew to permanently inhabit the space station.

ALLOCATED COSTS

Allocated costs cover the Small Business Innovative Research program set-aside percentage tax, the allocated costs of contract administration for NASA programs which the DCMC administers, some internal taxes (Center Director's Discretionary Fund), and the program mission support/research operations support which enable the NASA field centers to provide a basic level of housekeeping, engineering shop support and ADP services.

APA (Allowance for Program Adjustment)

Allowance for Program Adjustment covers items beyond the control of the program manager, such as changes in scope, reductions in the approved level of funding for the program, major changes in interfaces (e.g., performance changes in the launch vehicle causing a substantial redesign); in addition, APA has had inaccurate or biased/misleading information.

DEVELOPMENT

Provides for the design, development, testing, and production of test hardware and software, flight hardware and software, ground systems for operations, and integration and verification.

FACILITIES

Provides new brick and mortar construction or modifications to existing facilities.

INSTITUTIONAL

Provides for contract audit services, institutional research operations support, center project management support, and mandated agency "taxes," e.g., small business and innovative research.

OPERATIONS

Provides for the operations of the space station including: launch package checkout and processing, initial lay-in and follow-on spares, logistics and resupply, ground control operations, and sustaining engineering.

PAYLOADS

Provides for the design, development, and operations of NASA material and life sciences experiments and payloads, commercial/technology payloads, and enhanced use of Mir. International payloads are launched in the FY 00 timeframe. Out-year payloads are budgetary figures only.

RESERVES

Reserves covers the inherent risk in any estimate that there will be "make-work" changes, or that the schedule for accomplishing given tasks will take longer than expected, or that the underlying economics of the contractor's business base will change (not dramatically, but to a reasonable level of business base fluctuation), or that the materials/subcontracts prices will increase.

SCHEDULE ADJUSTMENT

Any calculated bottom-line set-over of the detailed baseline estimate.

TERMINATION

Provision for any anticipated contract termination or transition costs.

TRANSPORTATION

Shuttle hardware (e.g., orbiter mods, docking berthing systems) and integration requirements unique to the space station.

USER SUPPORT

Space Station provided hardware, software, and integration for the payload community. Includes the payload operations and integration complex, payload data services, science utilization management, elements of lab support equipment, payload processing, and integration.

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